Technical Report EL-93-1
January 1993

(2)

US Army Corps
of Engineers
Waterways Experiment
Station

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Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: 1991 Studies

by *Andrew C. Miller, Barry S. Payne*
Environmental Laboratory

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Prepared for U.S. Army Engineer District, St. Louis

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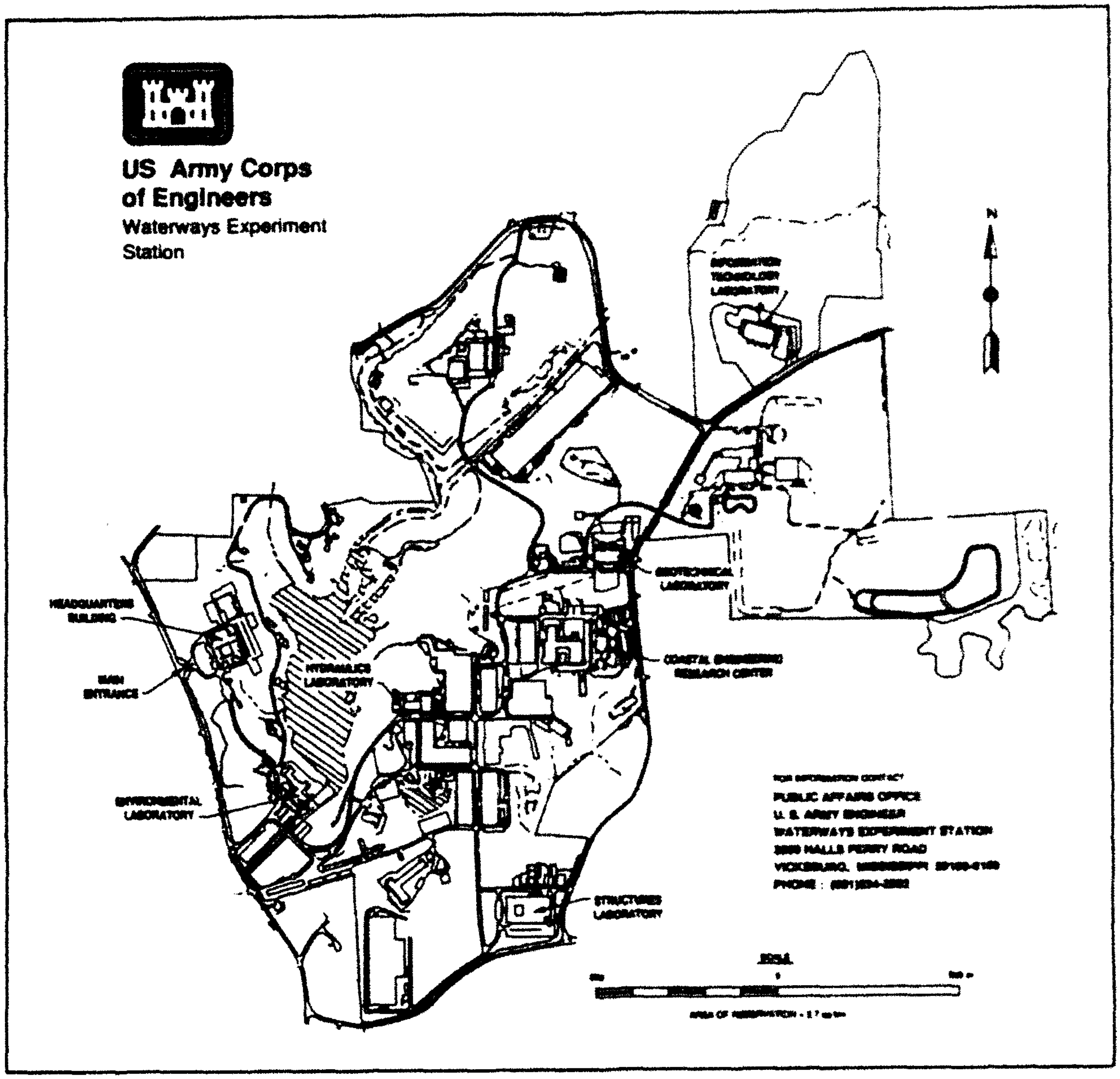
Prepared for U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833



Waterways Experiment Station Cataloging-in-Publication Data

Miller, Andrew C.
Effects of increased commercial navigation traffic on freshwater mussels in the upper Mississippi River : 1991 studies / by Andrew C. Miller, Barry S. Payne ; prepared for U.S. Army Engineer District, St. Louis.
137 p. : ill. ; 28 cm. — (Technical report ; EL-93-1)
Includes bibliographical references.
1. Freshwater mussels — Mississippi River — Effect of habitat on. 2. Mussels — Mississippi River — Effect of sediment on. 3. Unionidae — Effect of habitat on. 4. Inland navigation — Environmental aspects. I. Payne, Barry S. II. United States. Army. Corps of Engineers. St. Louis District. III. U.S. Army Engineer Waterways Experiment Station. IV. Title. V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL- -1.
TA7 W34 no.EL-93-1

PREFACE

In accord with the Endangered Species Act, Section 7, Consultation, personnel from the US Army Engineer District, St. Louis, and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated in the upper Mississippi River to assess the effects of existing and future increased traffic levels on freshwater mussels including *Lampsilis higginsi*. Concern had been expressed by the USFWS and other agencies that projected increases in commercial traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project, at Alton, IL (formerly known as Locks and Dam 26) could negatively affect freshwater mussels. In 1988, the St. Louis District contracted with the US Army Engineer Waterways Experiment Station (WES) to initiate these studies. The purpose of the 1988 studies was to identify sample sites for future work. This report describes results of the third full study year, which took place in 1991.

Divers for this study were Messrs. Larry Neill, Robert Warden, Larry Armstrong, and Dennis Baxter from the Tennessee Valley Authority. Mr. Todd Pedderson, Illinois Natural History Survey, Mr. Chris Weggs, Mississippi College, Jackson, MS, Dr. David Beckett, University of Southern Mississippi, Hattiesburg, MS, and Mr. Robert Read, Wisconsin Department of Natural Resources, assisted in the field. Ms. Sarah Wilkerson, Jackson State University, Jackson, MS, prepared all figures except maps, and Ms. Erica Hubertz, University of West Florida, identified and measured mussels in the laboratory at WES. Comments on an early draft of this report were provided by Mr. Dan Ragland, St. Louis District.

During the conduct of these studies, Dr. John Harrison was Director, Environmental Laboratory, (EL), WES, Dr. Conrad J. Kirby was Chief, Environmental Resources Division, EL, and Dr. Edwin Theriot was Chief of the Aquatic Habitat Group, EL. Authors of this report were Dr. Andrew C. Miller and Dr. Barry S. Payne, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

This report should be cited as follows:

> Miller, Andrew C., and Payne, Barry S. 1993. "Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: 1991 Studies," Technical Report EL-93-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

CONTENTS

LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To obtain
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers

EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: 1991 STUDIES

PART I: INTRODUCTION

Background

1. Operation of the second lock at the Melvin Price Locks and Dam (formerly the Locks and Dam 26 (Replacement) project) will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). Increased commercial traffic could detrimentally affect freshwater mussels (Mollusca:Unionidae), including *Lampsilis higginsi*, listed as endangered by the US Fish and Wildlife Service (USFWS) (1987). In accordance with the Endangered Species Act, Section 7, Consultation, personnel from the US Army Engineer District, St. Louis, and the USFWS determined that a monitoring program should be initiated to assess the effects of projected traffic levels on freshwater mussels including *L. higginsi*. Other agencies that participated in the development of this program included the US Army Engineer Divisions, Lower Mississippi Valley and North Central; US Army Engineer Districts, St. Paul and Rock Island; and State conservation agencies and interested lay personnel.

2. A reconnaissance survey to choose sample sites was conducted in 1988 (Miller et al. 1990) and also in 1989 (Miller and Payne 1991). Detailed quantitative and qualitative studies at selected mussel beds were initiated in 1989 and will continue through 1994 to obtain baseline data. This report contains a summary of data collected during the summer of 1991, the third full year of the project.

Study Design

3. Research was designed to obtain information on physical effects of commercial vessel passage (changes in water velocity and suspended solids near the substrate-water interface) at dense and diverse mussel beds in the UMR. In addition to physical studies, biotic parameters (species richness, species diversity, density, growth rate, population structure of dominant mussel species, etc.) are being monitored every second year. At each mussel bed, physical and biological data are being collected at a farshore (experimental) and nearshore (reference) site. Experimental sites are located close to the

navigation channel (affected by vessel passage), and reference sites are located as far as possible from the channel (affected to a lesser extent by vessel passage). The objective is to couple empirical data from physical and biological studies to make predictions of the physical effects of vessel passage on freshwater mussels.

4. Data are being collected to determine if commercial navigation traffic is negatively affecting *L. higginsi*. This is being accomplished by collecting information on all species of bivalves. As appropriate, results will be applied to *L. higginsi*. This surrogate species concept is being used since it is extremely difficult to obtain information on density, recruitment, etc., for uncommon species such as *L. higginsi*. In addition, intensive collections of this species would be detrimental to its continued existence. The following six parameters, considered to be indicative of the health of a mussel bed, are being used to determine if commercial navigation traffic is negatively affecting freshwater mussels.

a. Decrease in density of five common-to-abundant species.

b. Presence of *L. higginsi* (if within its range).

c. Live-to-recently-dead ratios for dominant species.

d. Loss of more than 25 percent of the mussel species.

e. Evidence of recent recruitment.

f. A significant change in growth rates or mortality of dominant species.

5. Each mussel bed will be studied every other year until 1994; therefore, 3 nonconsecutive years of data will be collected at each location. Data will be collected during a period when traffic levels are not expected to increase. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased by an average of one tow per day above the 1990 levels in the pool where monitoring takes place. Studies will then resume at the original rate and continue until 2040, the economic life of the Melvin Price Locks and Dam Project. Results of these studies will be reviewed annually to determine the need for altering sampling protocol. A preliminary schedule of studies to be conducted at each mussel bed appears in Table 1. A more complete description of these studies appears in Miller et al. (1990). Results of the 1989 studies are in Miller and Payne (1991), and results of the 1990 studies are in Miller and Payne (1992).

Purpose and Scope

6. The purpose of this research (1988-94) is to obtain baseline data on physical (water velocity and suspended solids) and biological conditions (density, species richness, relative species abundance, population demography of dominant species, etc.) at five mussel beds between river miles (RMs) 299 and 635 in the UMR. The purpose of the 1991 studies was to collect biological and physical data at a mussel bed in Pool 24 (approximately at RM 299), Pool 14 (approximately at RM 505), and Pool 10 (approximately at RM 635).

PART II: STUDY AREA AND METHODS

Study Area

7. The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. This habitat was altered as a result of passage of the Rivers and Harbors Act of 3 July 1930, which authorized the US Army Corps of Engineers to construct a navigation channel with a minimum depth of 9 ft* and a minimum width of 300 ft. Development of this navigation channel, which included placement of locks, dams, dikes, wing dams, and levees, converted the river to a series of run-of-the-river reservoirs characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically the upper reaches of pools in the UMR have relatively high water velocity and riverine conditions, whereas the lower reaches are more lake-like with deep, low-velocity water and fine-grained sediments (Eckblad 1986).

8. At sites investigated for this study, substrate in Pools 26-24 consisted mainly of coarse gravel, cobble, and slab rock. The channel was fairly narrow and deep with comparatively few side channels, island, or backwaters. Study sites in the middle reach of the UMR (Pools 22-17) were characterized by fine-grained sediments, numerous island, sloughs, and backwaters. The upper reach of the river at study sites in Pools 14, 12, and 10 was characterized by numerous islands, backwaters, sloughs, and beds of aquatic macrophytes. Substrate usually consisted of fine-grained sand and silt.

Study Sites

9. In 1988, preliminary data on physical and biological conditions were collected at mussel beds in Pools 26, 25, 24, 19, 18, 17, 14, 10, and 7. In 1989, additional preliminary studies were conducted in Pools 12 and 13. In these surveys, a combination of qualitative and quantitative techniques was employed to determine if a bed was suitable for detailed study. Based on information from these surveys, five mussel beds were chosen (Table 1, Figure 1).

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

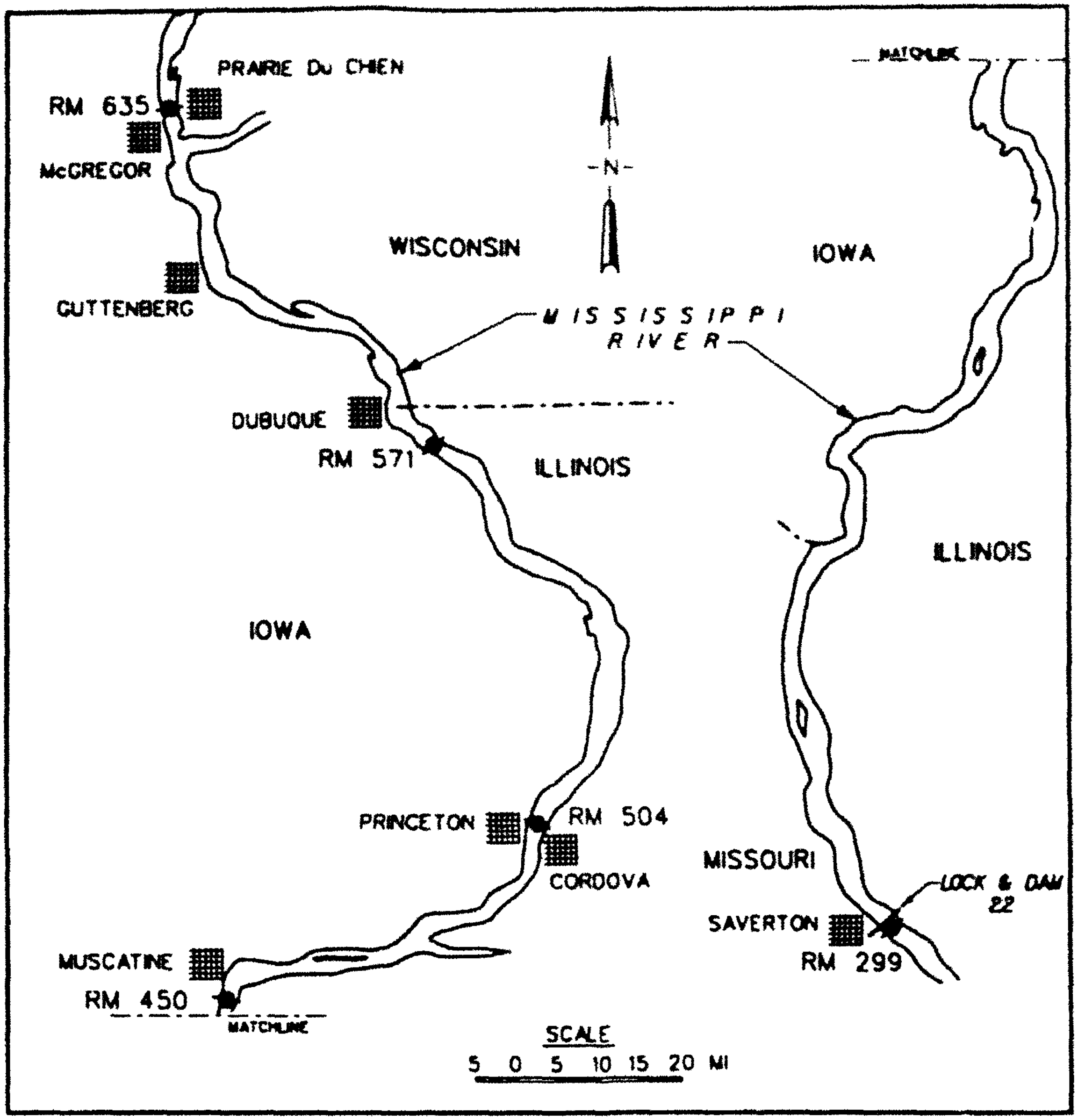


Figure 1. Location of the five mussel beds chosen for detailed study in the UMR, 1989-1994

10. Mussel beds chosen for study by representatives of the St. Louis District, US Army Engineer Waterways Experiment Station (WES), and USFWS are:

Pool	RM
24	299 RDB*
17	450 RDB
14	504 LDB*
12	571 RDB
10	635 RDB (Main Channel)

* RDB-Right descending bank; LDB-left descending bank.

A complete description of mussel beds in Pools 17 and 12 appears in Miller and Payne (1992); the following description applies only to the beds studied in 1991:

Pool 24

11. This mussel bed is located on the right descending bank (RDB) approximately 1.5 miles downriver of Lock and Dam 22 (Figure 2). A series of wing dams on the left descending band (LDB) directs water across the channel and toward the mussel bed. Commercial traffic must move along the RDB when approaching or exiting Lock and Dam 22. Substrate at this location consists of slab rock, coarse gravel, and sand. Ten quantitative and 18 qualitative samples were obtained at this bed in 1988. Sixty quantitative and 42 qualitative samples were collected in 1989. In 1991, 30 quantitative samples were taken at a nearshore (100 ft from the RDB) and a farshore site (200 ft from the RDB). In addition, 36 qualitative samples were obtained from this bed in 1991. Although *L. higginsi* has never been found in Pool 24, this bed contains a dense and diverse assemblage of mussels. This river reach was included so that representative data would be collected in the lower portion of the UMR.

Pool 14

12. An extensive mussel bed is located in the lower portion of Pool 14 on the LDB (Figure 3). This bed supports a dense and diverse assemblage of mussels including *L. higginsi*. Twenty quantitative and 27 qualitative samples were collected at this bed in 1988. Sixty quantitative and 59 qualitative samples were taken from the central portion of the mussel bed in 1989. In 1991, 30 quantitative samples were taken from a nearshore (160 ft from the LDB) and a farshore site (300 ft from the LDB) site. In addition, 48 qualitative samples were collected at this bed in 1991.

Pool 10

13. Near Prairie du Chien, WI, the UMR splits into an east and west or main channel (Figure 4). The east channel is slightly less deep and not as wide as the main channel, although during high water conditions, it is navigable. Sediments in both the east and main channel consist of sand and silt with less than 5 percent gravel by weight. Numerous sloughs, aquatic plant beds, and islands characterize this reach of the river.

14. Although samples for mussels have been collected in both the east and main channel for this project, sites in the main channel were used for the majority of detailed physical and biological studies. In 1988, 43 qualitative

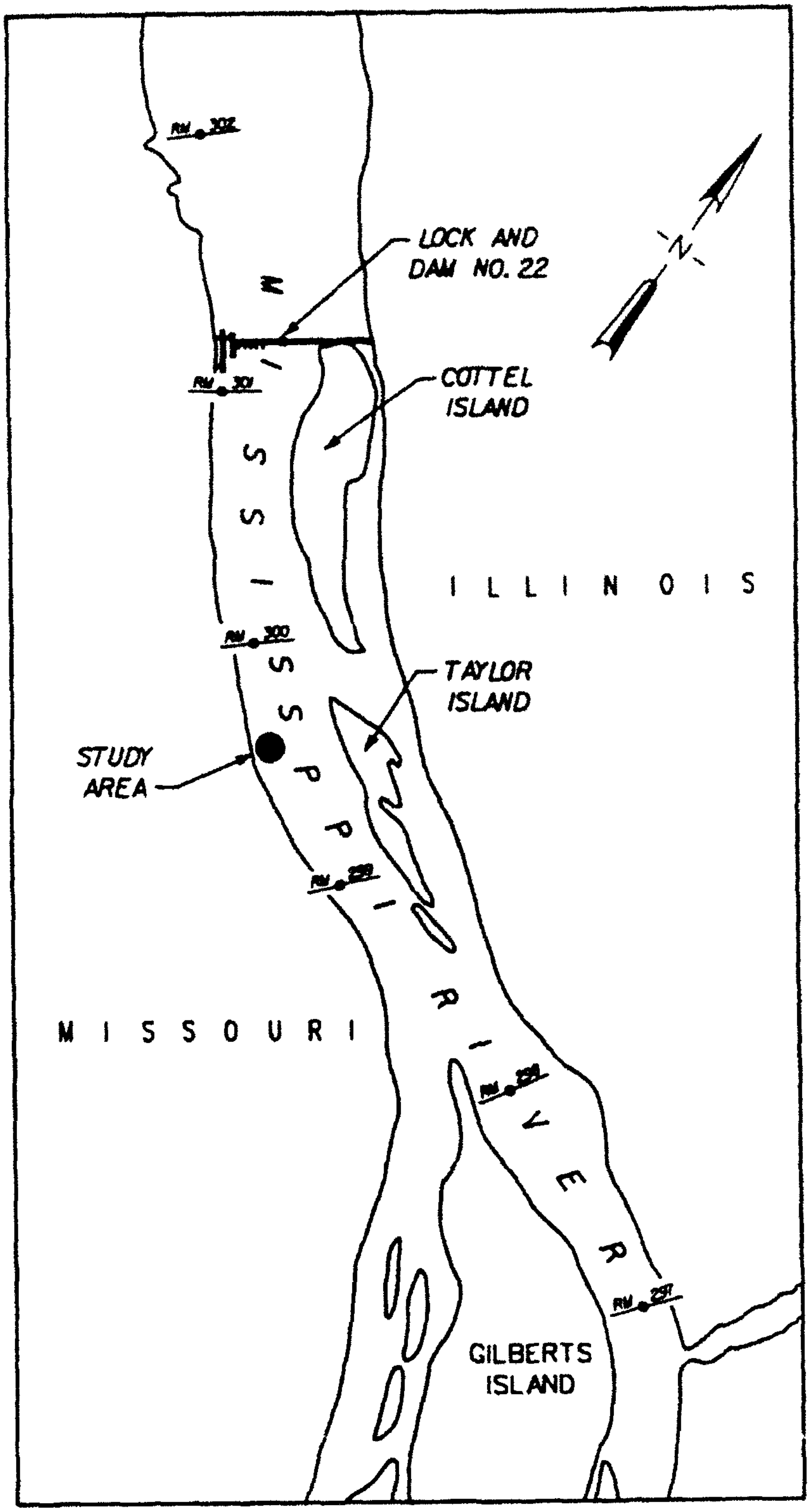


Figure 2. Study area at the mussel bed located in Pool 24, RM 299.6, 1991

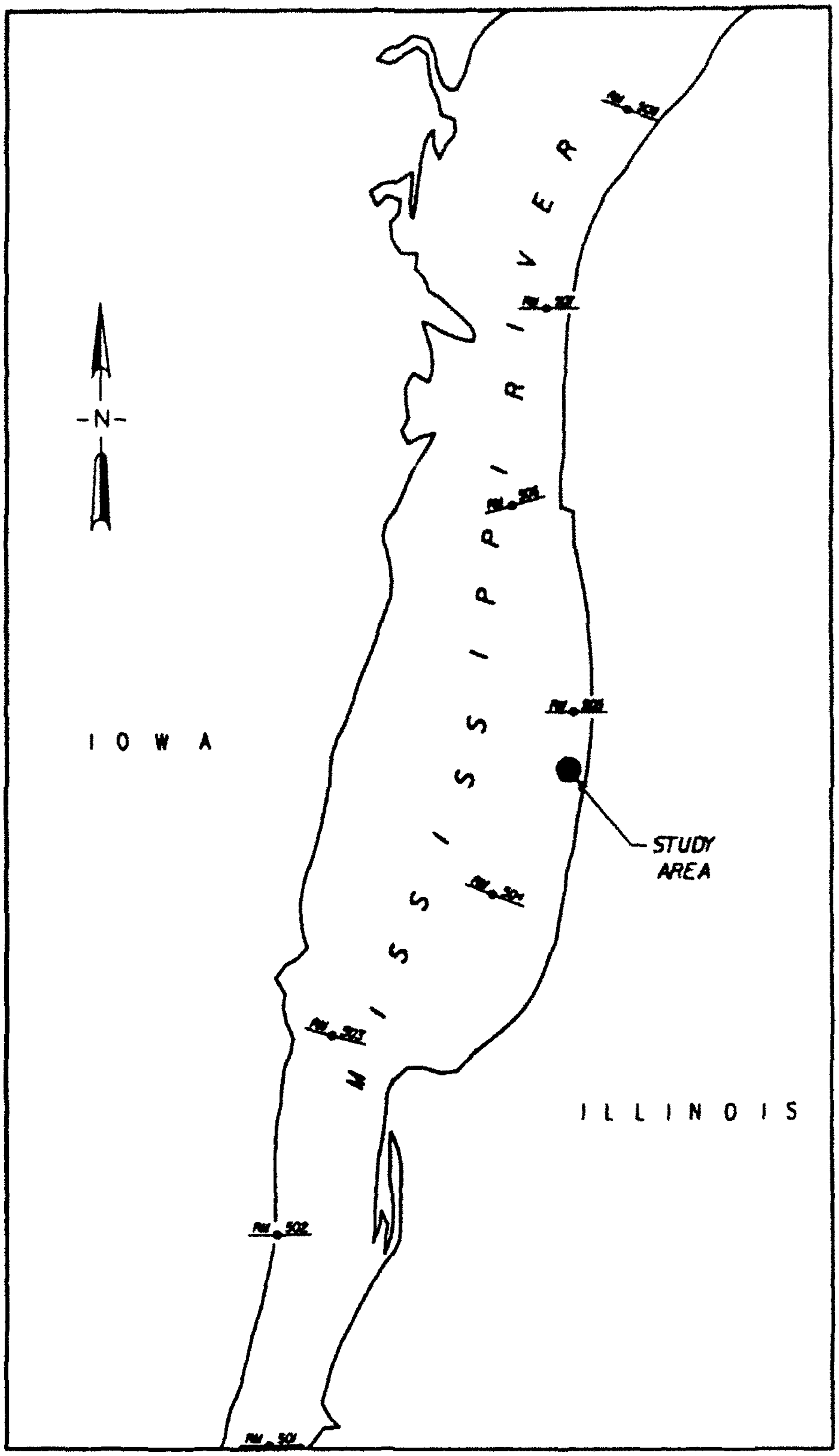


Figure 3. Study area at the mussel bed located in Pool 14, RM 504.8, 1991

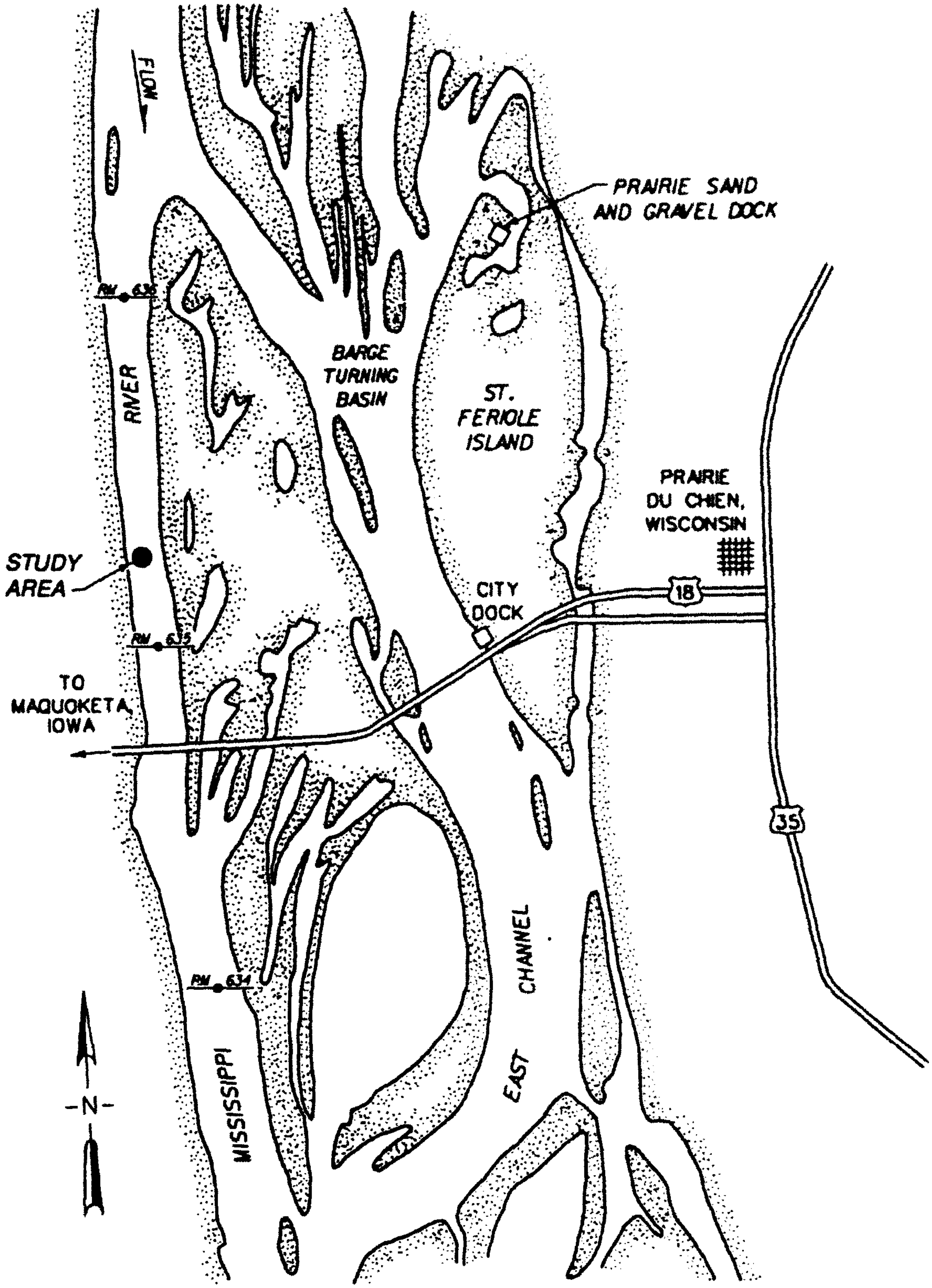


Figure 4. Study area at the mussel bed located in Pool 10, RM 635.2, 1991

samples were collected in the main channel of the river. No quantitative samples were collected in the main channel in 1988. In 1989, a total of 40 quantitative samples were collected at a nearshore (115 ft) and farshore site (180 ft) on the RDB of the river. In 1991, 30 quantitative samples were taken at a nearshore (75 ft from the RDB) and a farshore site (180 ft from the RDB). In addition, 48 qualitative samples were collected in 1991. Personnel at WES have also collected mussels in the east channel at a barge turning basin and a reference site located downriver.

Methods

Preliminary reconnaissance

15. A diver equipped with surface air supply and communication equipment made a preliminary survey of each study area before detailed studies began. He obtained information on substrate type, water velocity, and presence of mussels. A fathometer was used to measure water depth, and distance to shore was determined with an optical range finder. If the area appeared suitable, then detailed studies were initiated.

Qualitative collections

16. Qualitative samples were obtained by three divers working simultaneously (Table 2). Each diver was given four nylon bags and instructed to put approximately five mussels in the first bag and 20 mussels in each of the other three bags. Divers attempted to collect only live mussels, although dead shells were occasionally taken that had to be discarded. Collecting was done mainly by feel since water visibility was poor. Mussels were brought to surface, identified, and counted. Selected individuals were shucked and retained for voucher. Additional specimens were preserved in 10-percent buffered formalin and returned to the laboratory for analysis of physical condition (ratios of shell length to tissue dry mass, etc.). Unneeded specimens were returned to the river unharmed.

Quantitative sampling

17. At each site (nearshore or farshore), ten 0.25-m^2 quadrat samples were obtained at each of three subsites separated by 10 to 30 m. At each subsite, quadrats were placed approximately 1 m apart and arranged in a 2 by 5 matrix. A diver removed all sand, gravel, shells, and live molluscs within the quadrat. It usually took 5 to 10 min to clear the quadrat to a depth of 10 to 15 cm. All material was sent to the surface in a 20-ℓ bucket, taken to

shore, and sieved through a nested screen series (finest screen with apertures of 6.4 mm) and picked for live organisms. All bivalves were identified, and total shell length (SL) measured to the nearest 0.1 mm. All *L. higginsi* were returned to the river unharmed. Some of the bivalves were measured in the evening, then returned to the river the next day. Bivalves that could not be processed were preserved in 10-percent buffered Formalin and taken to WES for analysis. Notes were made on the number of "fresh dead mussels" (defined as dead individuals with tissue still attached to the valves).

<u>Growth studies</u>

18. In 1990, growth studies were initiated in Pool 14, Pool 17, Pool 12, and Pool 10. Demographically complete groups of dominant unionid species were collected, total SL was measured in the field, and each mussel was engraved with an identifying code using a dremel tool. At each nearshore and farshore site, three 0.25-m^2 aluminum quadrats were cabled together with 20 m of 3/8 in.-coated wire rope. The quadrats were secured to the river bottom, and all substrate (i.e., live bivalves, sand, and gravel) was excavated to a depth of 10 to 15 cm. Twenty liters of screened gravel (saved from the quantitative samples) and the marked mussels were placed in each quadrat.

19. In subsequent years, these sites were revisited and quadrats were retrieved. Mussels were measured and yearly growth rates computed. In addition to directly measuring growth by this technique, growth of dominant species was estimated by analysis of length frequency histograms and by measuring all interannular distances.

<u>Water velocity readings</u>

20. Water velocity was measured 23 cm above the substrate-water interface using a Marsh McBirney Model 527 current meter. The sensor for this instrument measures velocity in two directions (an X and Y component that are at right angles to each other) and is equipped with a compass. The compass, which is read from the meter, assists in positioning the sensor and can be used to calculate direction of flow. The meter sensor was mounted in a concrete block, positioned, and secured by divers. Two meters were equipped with 1,000 ft of cable, and two were equipped with 200 ft of cable. Water velocity in two directions and a compass reading were obtained at 1-sec intervals and stored on a model CR10 data logger (Campbell Scientific, Inc., Logan, UT). Data were downloaded to a Toshiba laptop personal computer for later analysis and plotting.

21. During 1991, the effects of commercial vessel passage on water velocity were studied at two mussel beds. Data were collected along the RDB at RM 299.4 (Pool 24) and at RM 504.7 (Pool 14). Up to four sensors were deployed at distances ranging from 50 to 400 ft from the bank. Sensors were never placed in the navigation channel. Each sensor was positioned to obtain velocity readings parallel to (pointing upriver) and at right angles (pointing into the channel) to the direction of flow.

22. The sensors were positioned at the beginning of the day and retrieved each evening. When a commercial vessel was sighted, the meters and data logger were turned on (usually about 250 sec before the vessel passed), and continuous data on water velocity and compass readings were obtained. Usually between 600 and 1,200 sec of data were collected for each vessel passage. Data on distance to shore, type of vessel, direction, etc., were recorded.

23. Velocity data and compass readings were converted to ASCII files, and magnitude of flow was calculated from individual velocity components by the formula:

$$\text{Magnitude} = (X^2 + Y^2)^{0.5} \tag{1}$$

The resolved angle of water flow was determined by the formulae:

$$0 = \text{TAN}^{-1}\,(X/Y) \text{ if } Y \geq 0\text{, or} \tag{2}$$

$$0 = \text{TAN}^{-1}\,(X/Y) + 180^\circ\text{, if } Y < 0 \tag{3}$$

24. Summary statistics (mean, standard deviation, minima, and maxima) were calculated for a time interval immediately before (or after) and during each event. The time interval before the event included 200 sec that ended at least 50 sec before the vessel reached the site. The time interval that included the event usually began 50 sec before the vessel reached the sensors and continued for up to 150 sec after the vessel passed. The magnitude of physical change associated with each passage could then be evaluated by

comparing summary statistics collected during the event with statistics obtained before (or after) the vessel passed.

25. In 1991, water velocity near the substrate water interface was measured using a Nixon microflow probe. This is a mechanical probe with a propeller diameter of 11 mm; hence it can be placed near the substrate-water interface. The purpose was to measure vessel-induced velocity changes as close as possible to the substrate where mussels were embedded. The Nixon velocity probe was also coupled to a data logger.

Data analysis

26. All bivalve data (lengths, weights, etc.) were entered on a spreadsheet and stored in ASCII files. Summary statistics were calculated using functions in the spreadsheets or with programs written in BASIC or SAS (Statistical Analysis System). All computations were accomplished with an IBM or compatible XT or AT personal computer. Biological and physical data were plotted directly from ASCII files using a Macintosh SE computer and a laser printer.

Community Characteristics-Qualitative Data

27. A total of 1,970 bivalves was collected in 132 separate qualitative samples at sites in Pools 24, 14, and 10 in July 1991 (Table 3). *Amblema plicata plicata* dominated, comprised 41.02 percent of the collection, and was found in 94.70 percent of the samples. Plotting the relative abundance of each species versus its rank for the entire qualitative collection (Figure 5) illustrates that the assemblage spanned three orders of magnitude. *Amblema plicata plicata* was approximately five times as abundant as the next common species, *Quadrula pustulosa*, which comprised 8.73 percent of the fauna. Fifteen species were common and comprised from 8.73 to 1.57 percent of the

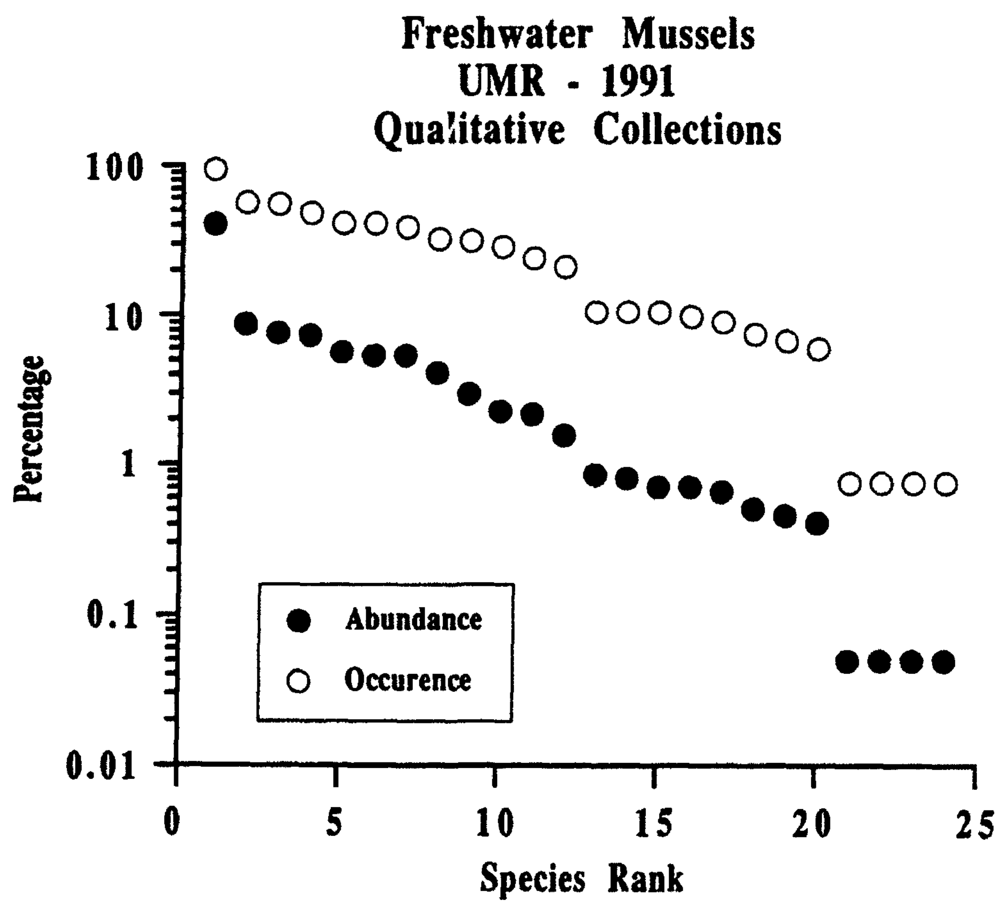


Figure 5. Percentage abundance and frequency of occurrence versus species rank for all mussels collected using qualitative methods at RM 299.6, 504.8, and 635.2 in the UMR, 1991

collection, and 12 species made up less than 1 percent of the assemblage. Although 23 species were collected, more than 64 percent of this fauna consisted of four species (Figure 5 and Table 3). The relationship between frequency of occurrence and species rank spanned two orders of magnitude (Figure 5 and Table 3). Fifteen species were found in more than 10 percent of the samples, and 10 species were found in more than 25 percent of the samples. Only one specimen of four species were taken in the total collection of 1,970 individuals.

28. The relationship between percentage abundance and species rank for the qualitative collection at each of the three sites studies in 1991 (RM 299.6, RM 504.8, and RM 635.2) appears in Figure 6 (also see Appendix A, Tables A1-A6). The collection from RM 635.2 was characterized by the strong dominance of a single species (*A. p. plicata*), whereas collections from the other two locations were more evenly distributed. Aside from this difference, distribution of species within the assemblage was relatively similar at all three beds.

29. A plot of cumulative species versus cumulative individuals (referred to as species-area curves) provides a mechanism for determining the difficulty of obtaining rare species. At the three sites where qualitative samples were taken, these relationships indicated that the majority of species present were found after 200 individuals had been collected (Figure 7). A determination of the relationship between species present and sampling effort provides an indication of the ability to collect uncommon species. This index can be used to evaluate the effects of commercial navigation traffic or other factors that alter habitat on the ability to find uncommon species.

Bivalve Density

30. At RM 299.6, total bivalve density at the nearshore site was significantly less ($P < 0.0001$) than at the farshore site (5.1 individuals/sq m) (Table 4 and Figure 8). There were no significant intersite differences ($P > 0.05$) at either RM 504.8 or 635.2 (Tables 5 and 6 and Figure 8). Freshwater mussels are found in a relatively narrow band along the shore, not in the main channel. The farshore site at RM 299.6 was on the outer periphery of the bed. At the other two mussel beds (located at RM 504.8 and RM 635.2), both nearshore and farshore sites were located away from the periphery of the

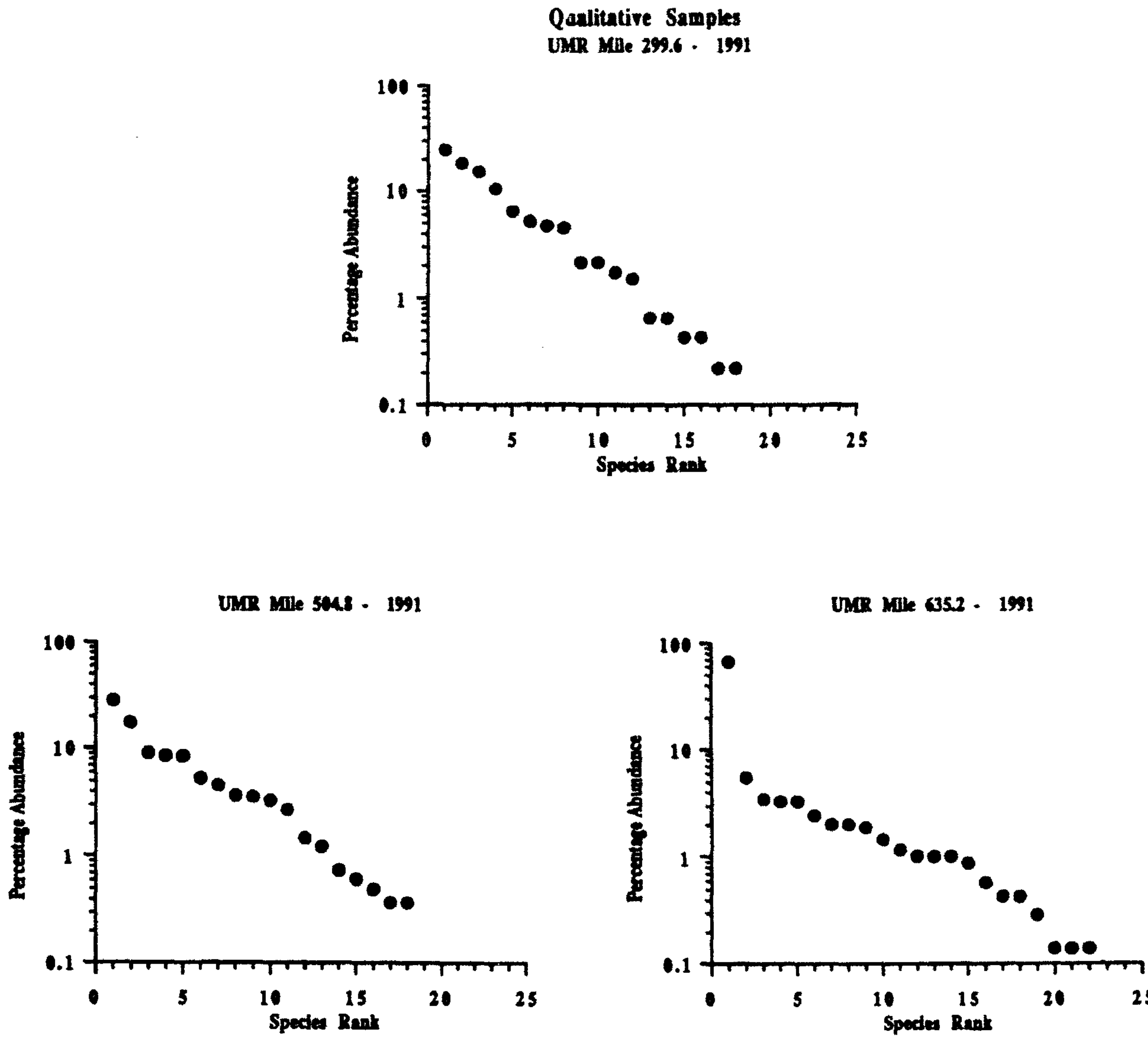


Figure 6. Percentage abundance versus species rank for mussels collected using qualitative methods at three locations in the UMR, 1991

bed. Percentage abundance of dominant unionids remained relatively similar at nearshore versus farshore site at RM 504.8 and 635.2 (Figure 9).

31. As the quantitative samples were processed, the number of fresh dead bivalves (individuals that were obviously dead but still had tissue within the valves) were enumerated (Table 7). As the results illustrate, there were few fresh dead mussels at any of these mussel beds. Information on abundance of fresh dead shells will be used to assess effects of commercial navigation traffic on native mussels.

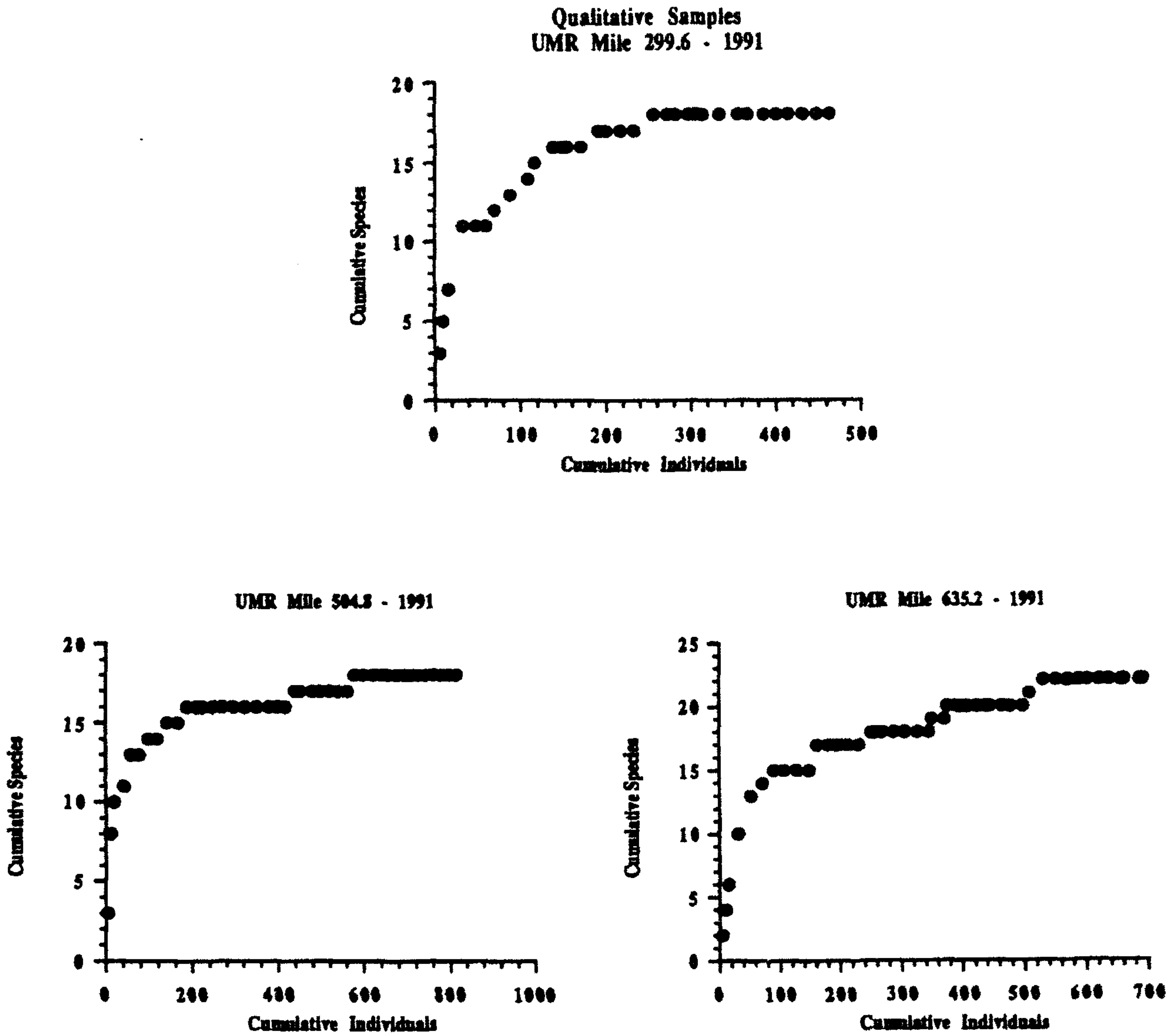


Figure 7. Cumulative species versus cumulative individuals based on qualitative sampling for freshwater mussels at three locations in the UMR, 1991

Community Characteristics-Quantitative Data

32. Relative abundance of dominant species at the three mussel beds studied in 1991 was relatively similar regardless of sampling technique (i.e., quantitative or qualitative, Figure 10). *Amblema plicata plicata* dominated at RM 635.2; *Obliquaria reflexa* and *Ellipsaria lineolata* became less abundant moving up river.

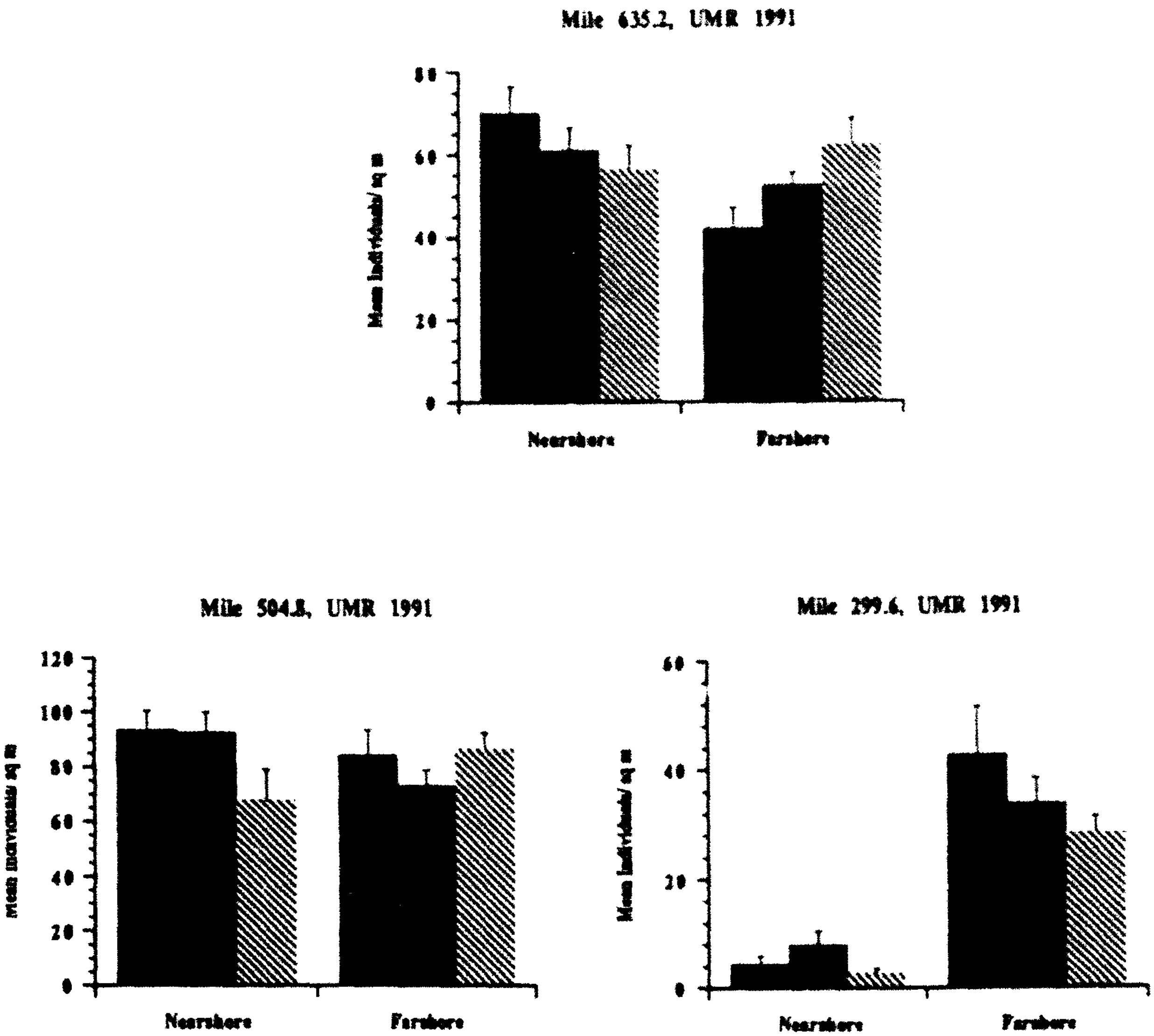
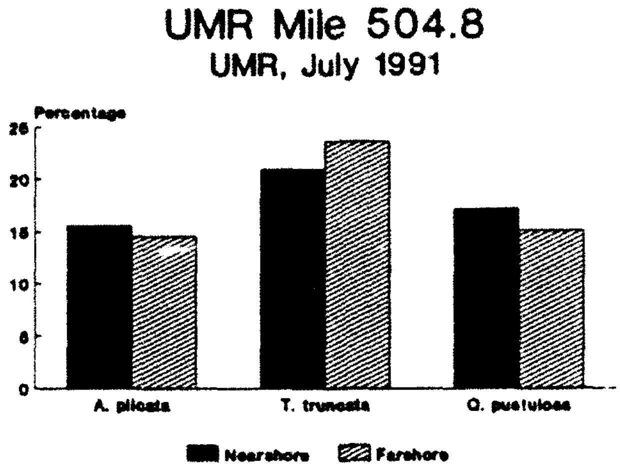


Figure 8. Mean density and standard error bars for freshwater mussels collected at three locations in the UMR, 1991

33. Species diversity (H') was moderate at RM 299.6 (2.29) and at RM 504.8 (2.37) but comparatively low at RM 635.2 (1.77) (see Tables B1-B3, Appendix B). Evenness (J), which can range from near 0 to near 1.0, was high at RM 299.6 and RM 504.8 (0.79 and 0.75), but low at RM 635.2 (0.56). Community indices were relatively similar regardless of whether qualitative or quantitative techniques were used (Figure 11). The bed at RM 635.2 showed a comparatively lower diversity and higher dominance value, mainly because of the high abundance of *A. p. plicata* (see also Tables B1-B3, Appendix B).



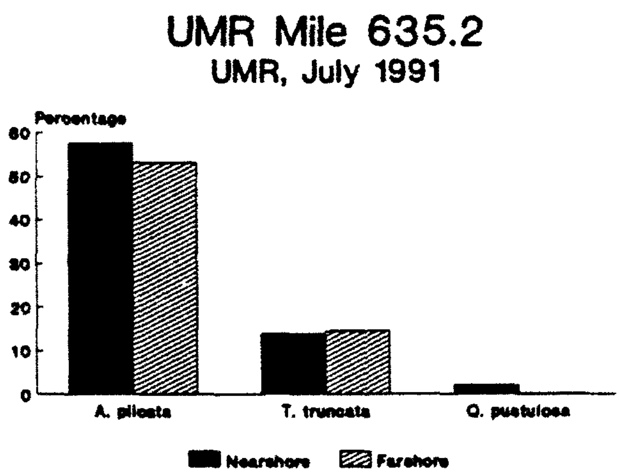
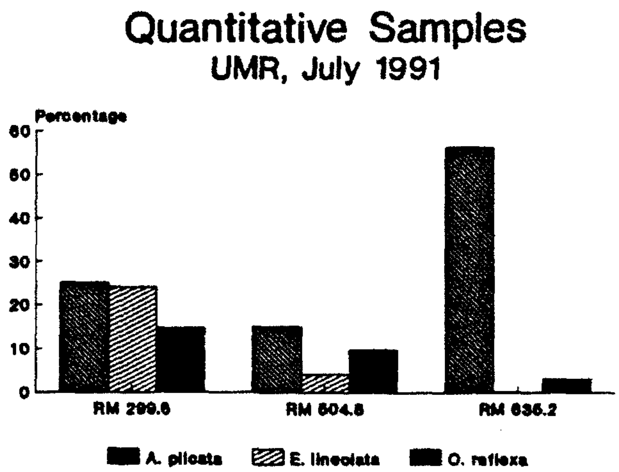


Figure 9. Relative species abundance of dominant unionids based on results of quantitative sampling at nearshore and farshore sites at two locations in the UMR, 1991

34. The number of individuals and species present that were less than 30 mm total SL can be used as an indication of recent recruitment and a measure of the overall health of the mussel bed. Percentage of individuals less than 30 mm ranged from 17.2 to 22.8 and were not substantially different among mussel beds (Tables B1-B3, Figure 12). The percentage of species present that had representatives less than 30 mm SL was similar at all mussel beds and ranged from 45.8 to 55.5 percent.



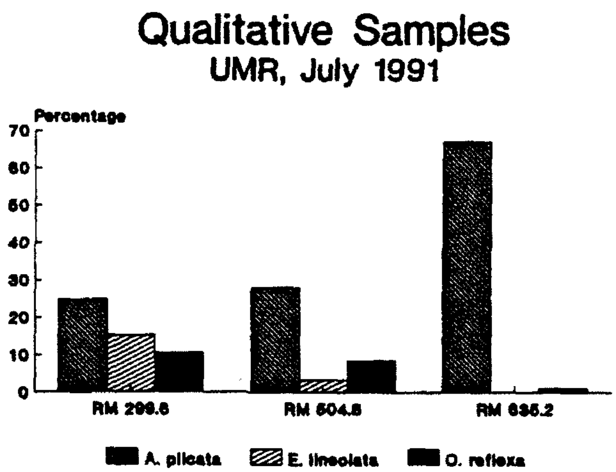


Figure 10. Relative species abundance of dominant unionids based on results of quantitative sampling at three locations in the UMR, 1991

35. Species area (Figure 13) and dominance-diversity plots (Figure 14) were prepared for the quantitative samples collected at the three mussel beds studied in 1991. Species area curves were similar for each bed; after approximately 250 individuals had been collected, the majority of the species had been found. Mussel community structure was similar at beds in Pools 24 and 14. The bed in Pool 10 exhibited a strong dominance by two species (*A. p. plicata* and *Truncilla truncata*). An examination of changes in the ability to collect uncommon species or the relationship between species rank and relative

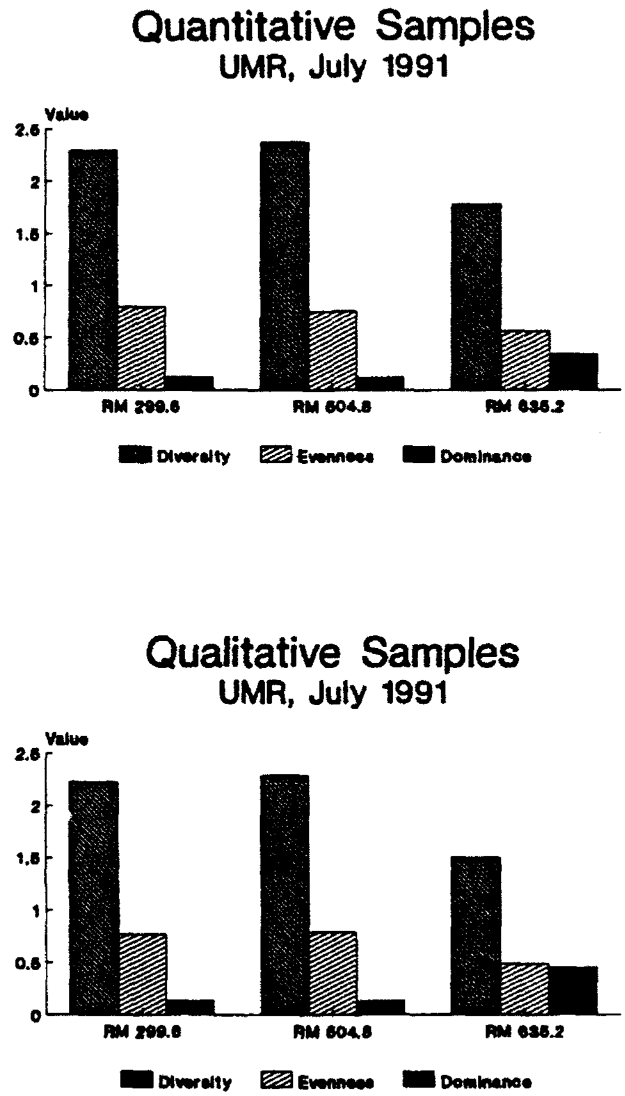


Figure 11. Community indices at three locations in the UMR based on the results of quantitative sampling, 1991

species abundance for the entire assemblage provides an indication of the overall stability of the mussel bed.

Presence of *Lampsilis higginsi*

36. *Lampsilis higginsi*, listed as endangered by the USFWS (1987), comprised 0.71 percent (14 individuals) and was found in nearly 10 percent of the qualitative samples (Table 3). *Lampsilis higginsi* ranked 16th out of 24 species of bivalves. Ten *L. higginsi* were collected using qualitative methods at

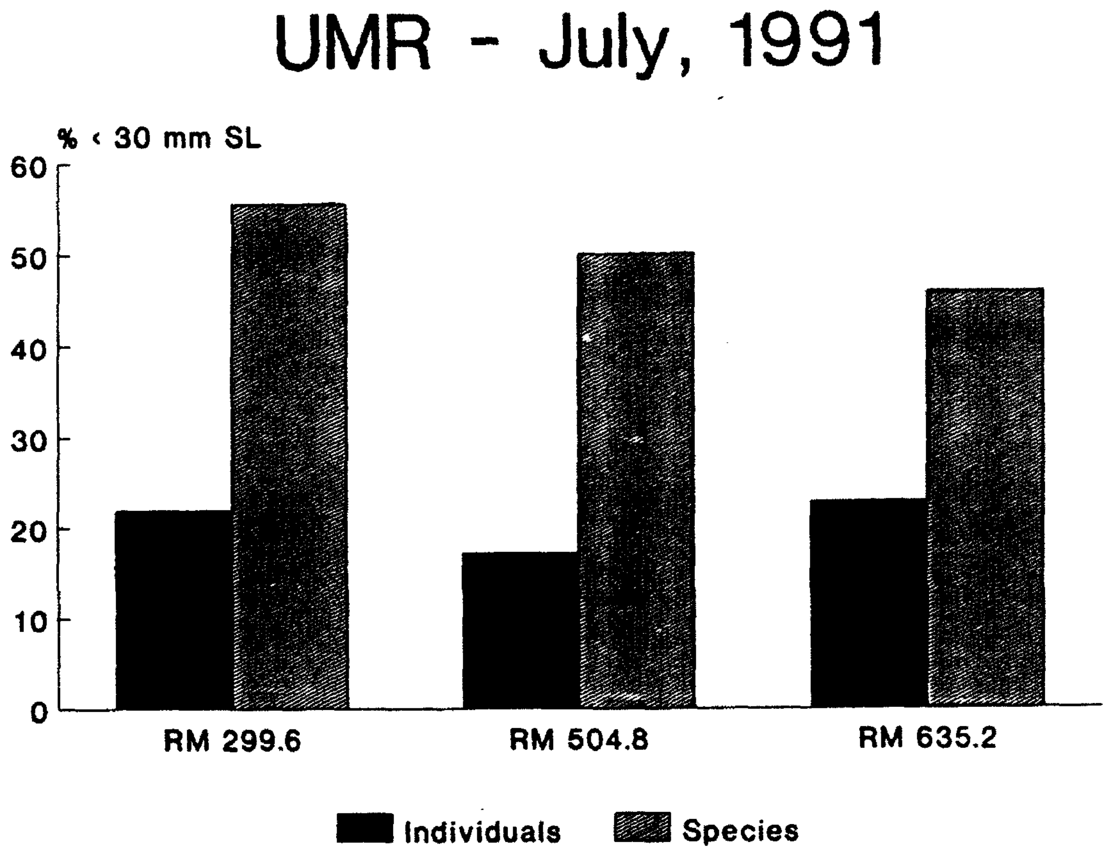


Figure 12. Percentage of individuals and species less than 30 mm total shell length at three locations in the UMR, 1991

RM 504.8 and four were collected at RM 635.2. Using quantitative methods, six and two individuals were collected at these two beds, respectively. *Lampsilis higginsi* has not been found at the mussel bed in RM 229.6. Table 8 includes a summary of *L. higginsi* collected in the past 3 years by WES personnel.

<u>Demographic Analysis</u>

37. The size demography of mussel populations was similar at nearshore and farshore sites for all species in all pools. Thus, the following analysis of size structure considers nearshore and farshore sites together. Size frequency histograms for mussels collected in 1991 appear in Appendix C.

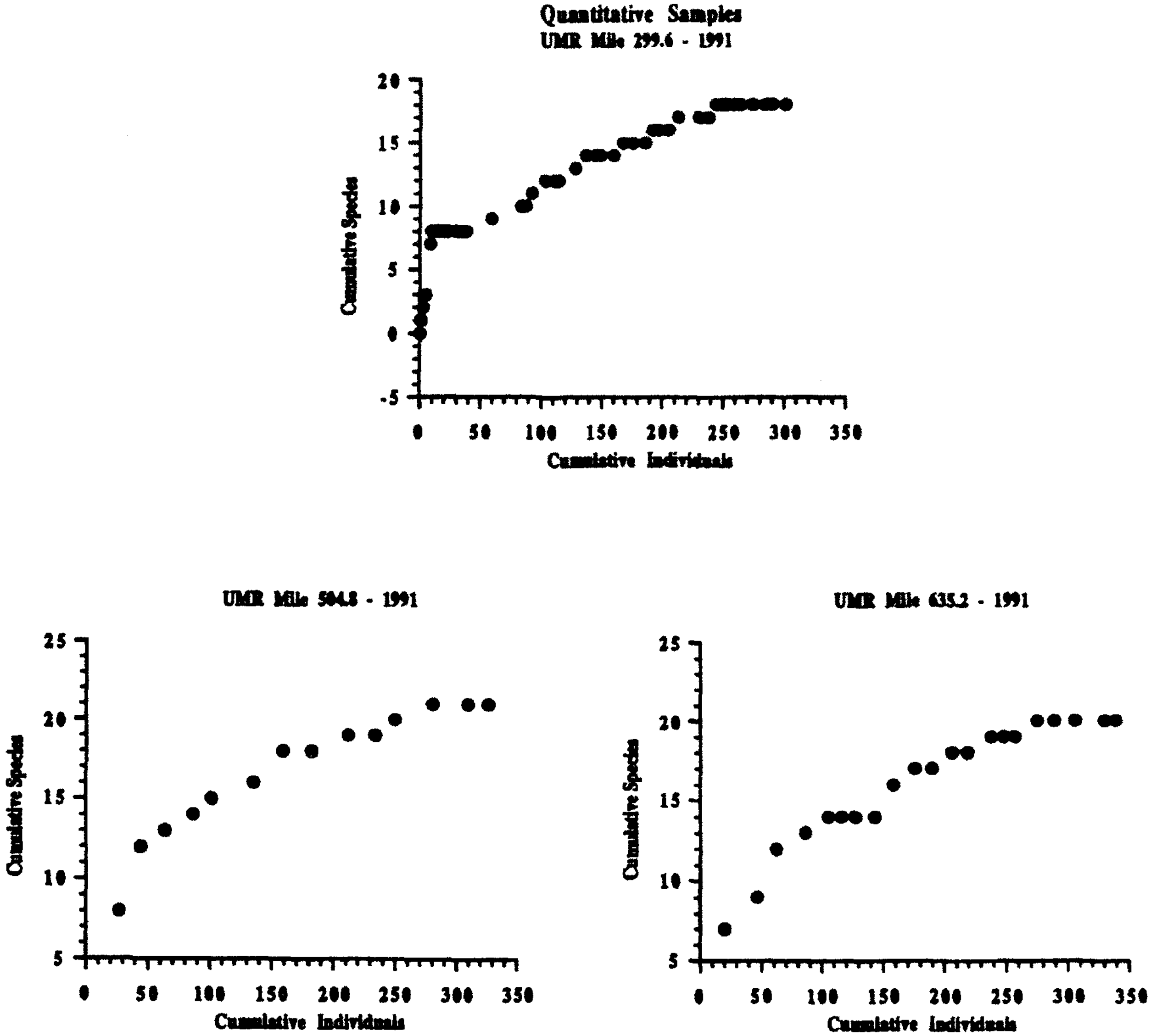


Figure 13. Cumulative species versus cumulative individuals based on quantitative sampling for freshwater mussels at three locations in the UMR, 1991

<u>Size demography of dominant unionids in Pool 24</u>

38. *Amblema plicata plicata*. Although the total size range of 66 individuals sampled from this population was 14 to 116 mm, 46 percent were represented by a single cohort of recent recruits ranging from 26 to 34 mm in length (Figure C1). This cohort probably represents 1989 recruitment, and growth of this single year class, because of its high relative abundance, should be easily monitored during subsequent years.

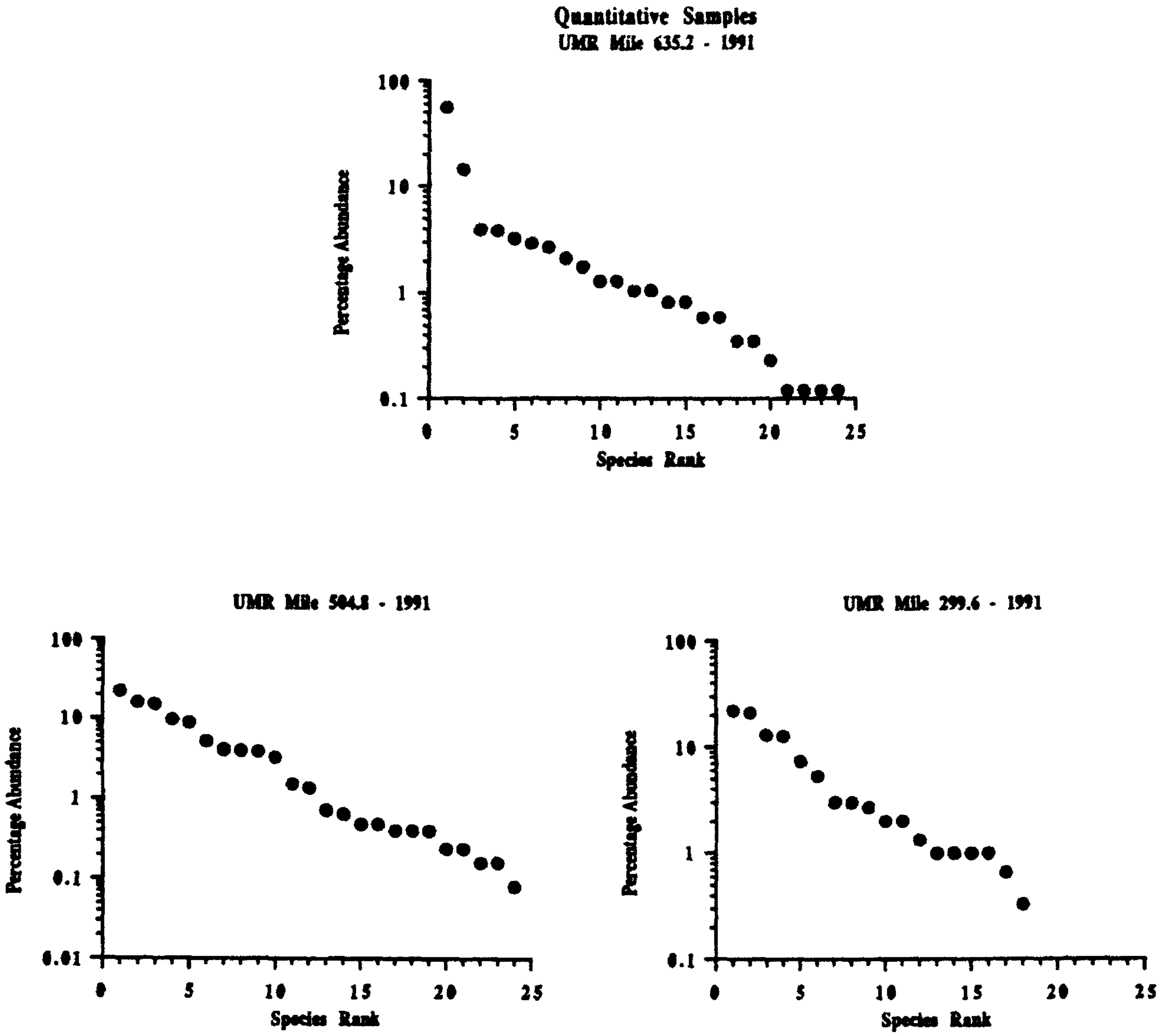


Figure 14. Percentage abundance versus species rank for mussels collected using quantitative methods at three locations in the UMR, 1991

39. *Corbicula fluminea*. Twenty-two individuals were obtained that appeared to represent a single cohort of this population (Figure C2). All twenty individuals ranged from just 8 to 14 mm in length.

40. *Ellipsaria lineolata*. Sixty-three individuals were obtained, and they ranged in length from 30 to 96 mm (Figure C3). The population structure provides evidence of constant annual recruitment.

41. *Obliquaria reflexa*. A small sample (39 individuals) could not be analyzed in detail. However, the most abundant cohort appeared to be centered

at 40 to 42 mm in length and probably represented mussels 3 or 4 years old (Figure C4).

42. *Truncilla truncata*. Only 38 individuals were obtained of this small species (Figure C5). Three of four cohorts appeared to be present ranging in size from 22 to 46 mm, suggesting a life span of 3 to 4 years.

Size demography of dominant unionids in Pool 14

43. *Amblema plicata plicata*. Three consecutive year classes of recent recruits were distinct and relatively abundant (Figure C6). Individuals centered at 16 to 18 mm in length probably represented 1990 recruits and comprised 9 percent of the population. The next larger cohort was centered at 26 to 28 mm in length, probably represented 1989 recruitment, and comprised 16 percent of the population. The third young cohort was centered at 36 to 40 mm in length, represented 1988 recruitment, and comprised 16 percent of the population. The regular spacing of these three distinct, young cohorts suggested an average annual growth increment of 10 mm during early life. Mussels ranging from 50 to 60 mm in length were not abundant relative to both smaller and larger size classes, and this paucity of intermediate-size mussels probably reflects a year or two of poor recruitment. The remainder of the population was comprised mostly of mussels 60 to 90 mm in length, with the largest individual measuring 102 mm in length. As for most long-lived species, the relatively small annual increment of growth during later life makes it impossible to distinguish individual year classes among large, old individuals.

44. *Ellipsaria lineolata*. The 51 individuals obtained of this species ranged from 12 to 84 mm in length (Figure C7). Most mussels were 32 to 66 mm long. Some recent recruitment was clearly indicated by the presence of individuals just 12 to 20 mm long.

45. *Fusconaia flava*. A sample of 65 individuals represented a size range of 16 to 76 mm (Figure C8). Detailed analysis of demography was not possible because individual cohorts could not clearly be distinguished.

46. *Leptodea fragilis*. Thirty-eight of 50 individuals collected were less than 64 mm in length, and the largest mussel obtained was 94 mm in length (Figure C9). This species population showed evidence of constant annual recruitment.

47. *Megalonaias nervosa*. Forty-one individuals were collected ranging from 32 to 138 mm in length (Figure C10). This species population showed evidence of constant annual recruitment.

48. *Obliquaria reflexa*. A large sample (122 individuals) was obtained. The population appeared to include four cohorts, centered at 20, 34, 42, and 50 mm length, respectively (Figure C11). Longevity of approximately 4 years, indicated by the four cohorts, is not unreasonable for this moderately small unionid.

49. *Obovaria olivaria*. Although 49 individuals were obtained, not much pattern could be distinguished in population size demography (Figure C12). Mussels ranging only from 50 to 60 mm in length comprised 73 percent of a population with total size range of 36 to 62 mm. High relative abundance of these moderately large individuals probably obscured patterns that otherwise would be detectable.

50. *Quadrula pustulosa*. Evidence of moderately strong recent recruitment was apparent for this species (Figure C13). Six percent of this population was represented by the 1990 cohort that ranged in length from 8 to 14 mm. The 1989 cohort ranged from 16 to 20 mm in length and contributed another 6 percent of the total sample. Multiple year classes were represented among the remaining individuals that ranged up to 62 mm in length.

51. *Quadrula quadrula*. Like *Q. pustulosa*, *Q. quadrula* showed evidence of moderately strong recent recruitment, with mussels from 16 to 24 mm in length comprising 8 percent of the population (Figure C14). Mussels of all sizes from 16 to 86 mm in length were amply represented in the sample, indicating generally consistent annual recruitment.

52. *Truncilla truncata*. A large sample (277 individuals) indicated two and possibly three cohorts (Figure C15). The smallest cohort was centered at 20 to 22 mm in length and comprised approximately 26 percent of the population. The next largest cohort was centered at 32 to 40 mm length and comprised an additional 70 percent of the population. A third and larger cohort, centered at 46 mm length, was suggested by a "shoulder" on the upper end of the size distribution of the abundant, intermediate-size cohort. The three possible cohorts probably represent 1990, 1989, and 1988 recruitment, respectively.

Size demography of dominant unionids at RM 635.2 in Pool 10

53. *Amblema plicata plicata*. A total of 479 individuals of this species were obtained (Figure C16), and recent recruitment was strong. The smallest cohort, probably representing 1990 recruits, was centered at 12 to 18 mm in length. This cohort comprised 14 percent of the total population. Of

approximately equal relative abundance (15 percent) was the next largest cohort of 1989 recruits centered at 28 to 34 mm in length. The 1988 year class was not as abundant (4 percent), but could be distinguished as a minor cohort centered at 44 to 48 mm in length. The regular spacing of these three smallest cohorts indicates an average annual growth increment of approximately 16 mm during the first few years of life. The remaining 67 percent of the population ranged from 52 to 110 mm in length and was comprised of several adjacent cohorts whose size distributions overlapped too extensively to allow individual cohorts to be distinguished.

54. *Fusconaia flava*. As for *A. p. plicata*, *F. flava* showed evidence of recent and relatively strong recruitment and included larger individuals (up to 72 mm long, Figure C17). The relatively small sample size did not allow detailed analysis of size demography.

55. *Leptodea fragilis*. Thirty-three individuals were collected ranging from 20 to 94 mm in length (Figure C18). Detailed analysis was not possible because there were few individuals in the sample.

56. *Megalonaias nervosa*. A small sample (34 individuals) of this species indicated a size range of 18 to 138 mm without any major gaps (Figure C19). Thus consistent annual recruitment was indicated.

57. *Obliquaria reflexa*. Only 28 individuals were collected of this moderately small species (Figure C20). Slight discontinuities in size distribution suggested three distinct cohorts centered at 22 to 26 mm, 32 to 36 mm, and 42 to 50 mm in length, respectively.

58. *Potamilus alatus*. Only 25 individuals were obtained of this species (Figure C21). The total size range was 52 to 118 mm in length, with 76 percent of the population ranging only from 62 to 84 mm in length.

59. *Truncilla truncata*. The maximum size of 58 mm observed is a reasonable approximation of the maximum length usually achieved by *T. truncata* (Figure C22). A large sample (123 individuals) accommodated relatively detailed analysis. Two abundant cohorts were clearly evident; the smaller was centered at 20 to 24 mm in length, and the larger at approximately 38 mm in length. A third and much less abundant cohort with average SL of approximately 46 mm was also identified. If these three cohorts are assumed to represent 1990, 1989, 1988 cohorts, the low relative abundance of the oldest and largest cohort suggests that only a few individuals live 3 years.

PART IV: PHYSICAL EFFECTS OF COMMERCIAL VESSEL PASSAGE

Background

60. Water velocity was measured with the Model S27 Marsh McBinney current meter at two to four locations (on a transect running from near to far-shore) for 29 vessel passages in July 1991 (Table 9). Data were collected at RM 299.4 (Pool 24) and RM 504.7 (Pool 14). Sensors were placed at distances ranging from 50 to 400 ft from the bank. Water velocity data were collected where there were diverse mussel assemblages; quantitative data on mussels were obtained 100 and 200 ft from the RDB at RM 299.6, and 160 and 300 ft from the RDB at RM 504.8 (Table 2). A summary of information on vessel passages appears in Table 9. Summary statistics for selected passages appear in Appendix D, and individual plots of water velocity appear in Appendix E. Each vessel passage event was labeled a test; these are numbered consecutively.

61. Plates in Appendix E are arranged as follows: the top two figures contain individual X-Y plots for velocity, the middle two figures contain the net or combined velocity, and the bottom two contain the compass direction. Four sensors were deployed for Tests 1-9 and Tests 18 and 19; two sensors were deployed for Tests 10-14 and 20-29. Only a single sensor was deployed for Tests 15-17.

62. Tests were divided into two groups: those in which vessel passage caused little or no change in ambient water velocity, and those that caused minor but measurable change in water velocity. Selected passage events in which there were no measurable changes in velocity (Tests 1, 9, 11, 16, and 20-24) were not plotted.

Events Causing Little or No Measurable Effects

63. Twenty-three passages were classified as having caused little or no measurable change in velocity. Twelve of these were plotted; the test number and corresponding figures are as follows: Test 2 (Figures E1 and E2), Test 3 (Figures E3 and E4), Test 5 (Figures E7 and E8), Test 6 (Figure E9), Test 10 (Figure E14), Test 12 (Figure E15), Test 14 (Figures E16), Test 18 (Figures E19 and E20), Test 19 (Figure E21), Test 25 (Figure E22), Test 27 (Figure E24) and Test 29 (Figure E25) (Appendix E). Situations such as these were caused by the vessel passing too far into the channel to have a nearshore effect, or

if water levels and velocities were such that only minor (not measurable) effects took place. As an example of a minor change in velocity, see the plot of data collected at sensor 940 for Test 10 (Figure E14). A slight decrease in velocity was noted on the X-axis and the combined (net velocity) during and immediately after passage.

Minor Effect of Vessel Passage

64. Six vessel passages caused minor changes to water velocity that was discernible at one or more sensors. Minor velocity changes were noted for Test 4 (Figures E5 and E6), Test 7 (Figures E10 and E11), Test 8 (Figures E12 and E13), Test 15 (Figure E17), Test 17 (Figure E18), and Test 26 (Figure E23). These are examples of water velocity changes caused by vessel movement that was barely measurable. For example, the mean combined velocity in Test 4, Sensor 942 (Figure E5), as the vessel passed was 1.83 ft/sec. After the vessel had passed out of the area, the mean combined velocity increased to 2.01 ft/sec. A downbound vessel caused a decrease in ambient velocity. This is because the vessel displaces water, which moves upstream, temporarily negating normal flow (see also Test 7, Figure E10). These velocity measures were made where freshwater mussels were found. Changes in velocity associated with vessel movement were usually 100 sec or less.

65. An upbound vessel caused an increase in velocity because water displacement moves downriver (see Figure E17, Test 15). Mean velocity on the Y-component during this vessel passage was 0.71 ft/sec. After the vessel had passed, mean velocity was approximately 50 percent of this value, or 0.43 ft/sec. This change was apparent in the combined velocity, although not in direction of flow (bottom figure in Figure E17). None of the water velocity changes noted during 1991 were as extensive as those found in 1990 (Miller and Payne 1992).

PART V: DISCUSSION

Background

66. The purpose of this research is to document important biotic and physical attributes at prominent mussel beds in the UMR. This information will be used to determine if biological conditions have changed through time as a result of disturbance caused by movement of commercial vessels. Six attributes of mussel assemblages were identified for use in evaluating change. Physical effects studies being conducted at beds where biological data are collected are being used for analysis of cause and effect. Although more data must be collected, recently collected information can be used to evaluate conditions at these beds. The purpose of the following section is to examine the six attributes of the mussel fauna at these beds using data collected since 1988.

The Six Attributes of Healthy Mussel Beds

Decrease in density of five common-to-abundant species

67. For this attribute, both density (individuals per sq m) as well as relative species abundance (percent composition of species in a mussel bed) will be considered. At RMs 299 and 504, density changes since 1988 of three common species (*T. truncata*, *O. reflexa*, and *E. lineolata*) were variable and showed no specific trends (Figure 15). At RM 504, densities of *T. truncata*, *O. reflexa*, and *E. lineolata* (relatively short-lived species) have actually increased through time. At RM 299, densities have either stayed the same or decreased. At RM 504, these three species have remained at about the same percentage of the fauna, although year-to-year densities show moderate increase (Figure 16). At RM 299, the relative abundance of these three species has remained essentially the same since 1988 (Figure 16). Although only 2 years of data are available for the main channel of the UMR at Mile 635.2, it is apparent that there have been no dramatic changes in relative species abundance of five dominant species between 1989 and 1991 (Figure 17).

68. Data from qualitative sampling can also be used to evaluate changes in relative species abundance. At RM 299, the abundance of *E. lineolata* appears to have declined slightly compared with the other species (Figure 18).

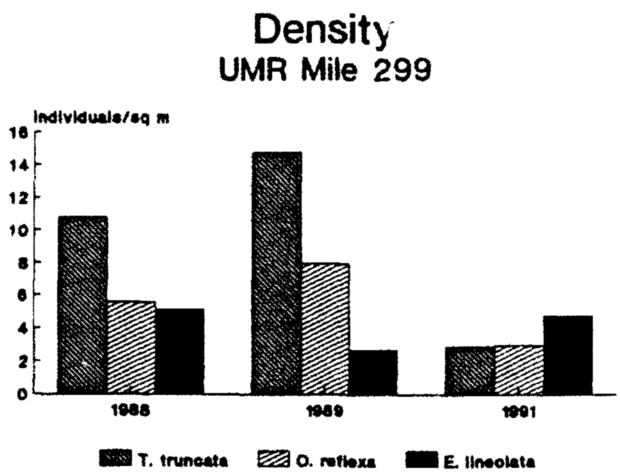
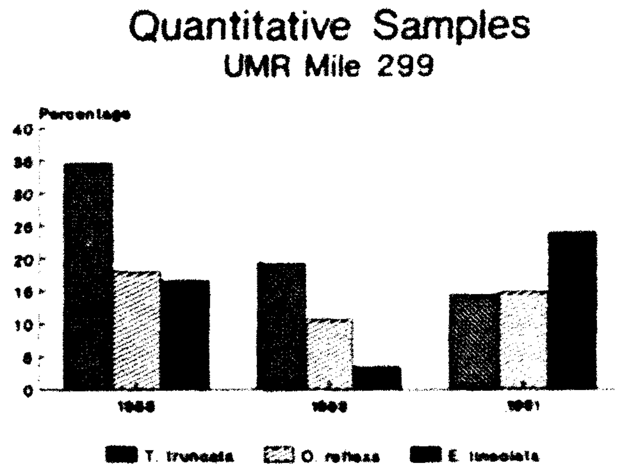


Figure 15. Mean density of dominant unionid species at two locations in the UMR, 1991

At RM 504, relative species abundance remained relatively similar for the 3 years except for 1989 when *O. reflexa* was comparatively high and *E. lineolata* was comparatively low. Only minor changes in community composition were noted between 1989 and 1991 at RM 635.2 (Figure 19).

69. In summary, relative species abundance or dramatic changes in density have not been noted based on the information collected to date. It is likely that inter-year variation, mainly because of having collected at slightly different locations each year, is due to chance variations. Changes in relative abundance of relatively short-lived species (for example *T. truncata*) are reasonable, especially since they do not always successfully recruit in large numbers each year.



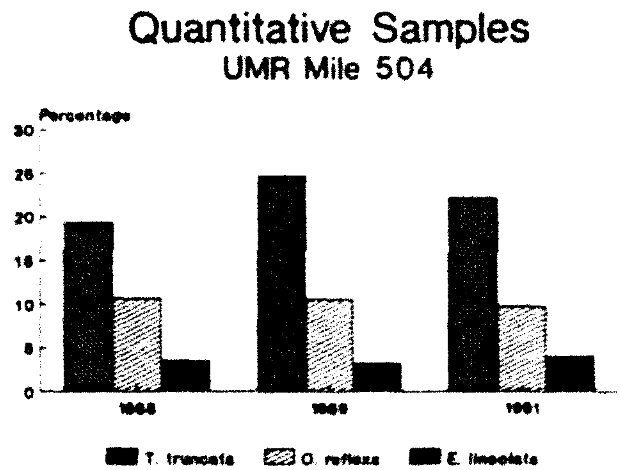


Figure 16. Percentage abundance of dominant species in 1988, 1989, and 1991 at two locations in the UMR, 1991

Presence of *L. higginsi* (if within its range)

70. *Lampsilis higginsi* appears to comprise about 0.5 percent of the assemblage in quantitative samples, and often more than 1 percent of the fauna in qualitative samples (Table 8). Because the divers tend to collect fewer small species (*Truncilla* spp) when sampling qualitatively, the relative abundance of larger size individuals, such as *L. higginsi*, will be slightly greater. Although this species has never been abundant in large rivers (Higgins' Eye Mussel Recovery Team 1982), its numbers do not appear to be changing based on these data.

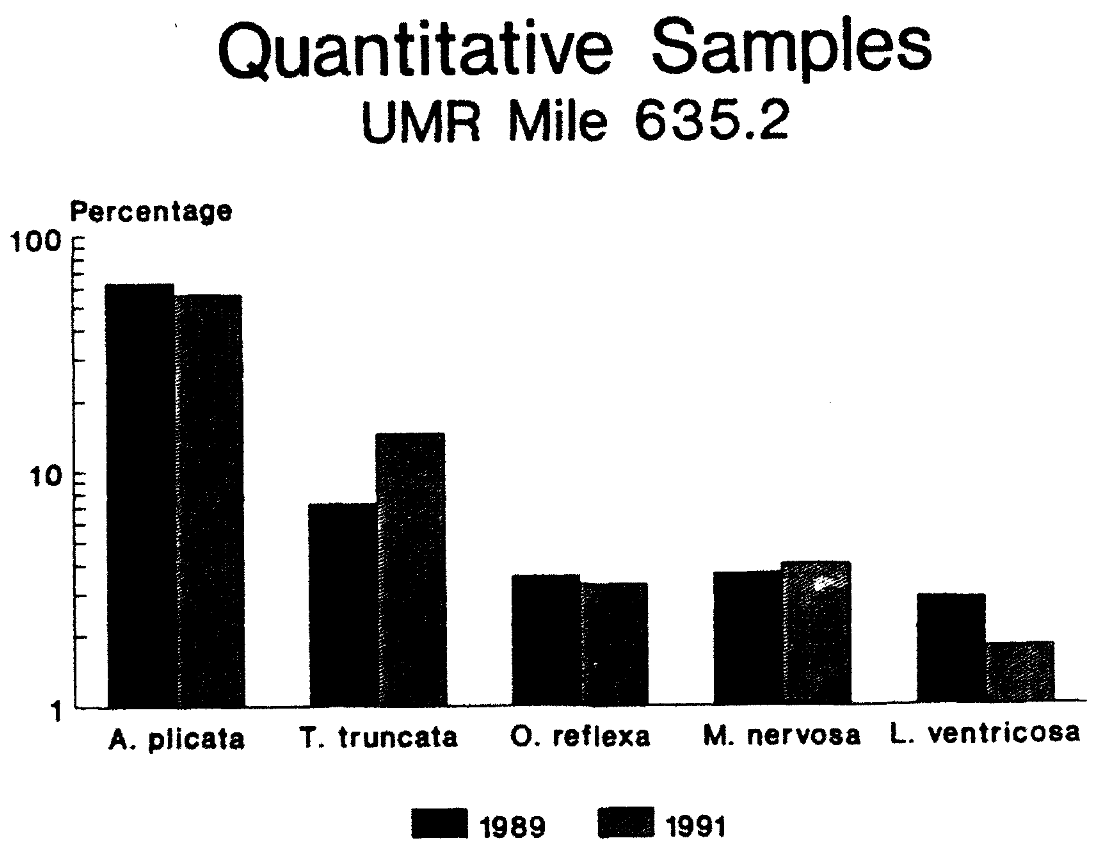


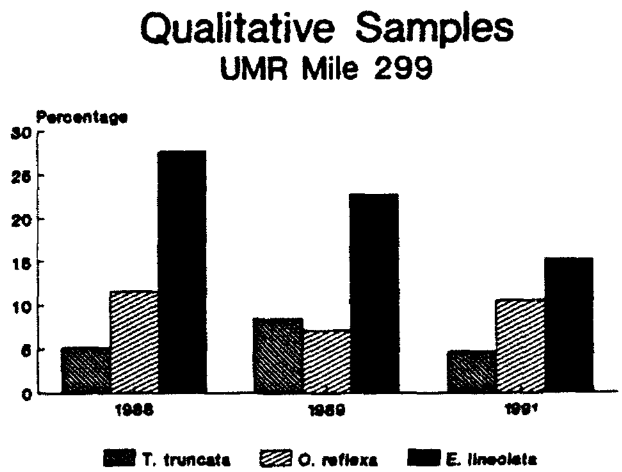
Figure 17. Percentage abundance of dominant species in 1989 and 1991 in quartitative samples at RM 635.2 in the UMR, 1991

Live-to-recently-dead
<u>ratios for dominant species</u>

71. In quantitative samples taken in the UMR, often more than 50 percent of the shells can be considered "relics" and may have been dead for many years. One objective of this research is to quantify the number of "fresh dead" mussels taken in the quantitative samples. These are defined as mussels that are dead but still have tissue attached to the shells. Recently dead mussels comprised less than 1 percent of the samples (Table 7), which was similar to findings in 1990.

Loss of more than
<u>25 percent of the mussel species</u>

72. The number of species collected is directly related to the number of individuals collected. Based on quantitative samples taken at RM 299, the number of species appeared to increase between 1988 and 1989 (Figure 20).



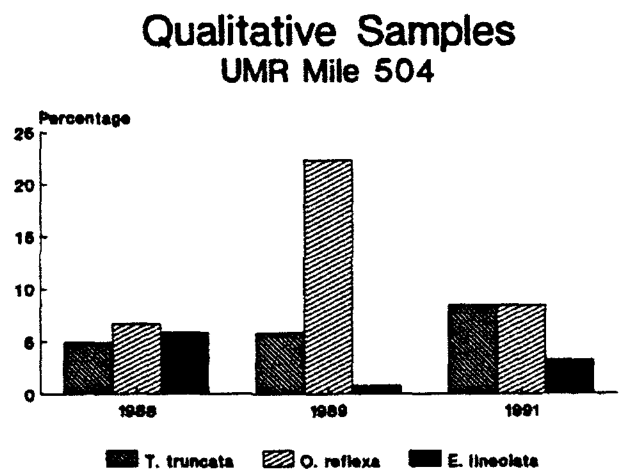


Figure 18. Percentage abundance of dominant species in 1988, 1989, and 1991 at RM 299 and 504 in the UMR, 1991

However, more individuals were collected in the latter year providing an opportunity to collect more species. The number of species and individuals collected using quantitative methods was only slightly greater at RM 504 in 1989 and 1991 than in 1988 (Figure 20). The number of species collected using qualitative methods (usually a greater number of individuals are taken allowing for more species to be found) was similar in all study years at RM 299 and RM 504 (Figure 21). Species diversity and evenness have remained relatively the same for all study years at RMs 299 and 504 (Figure 22).

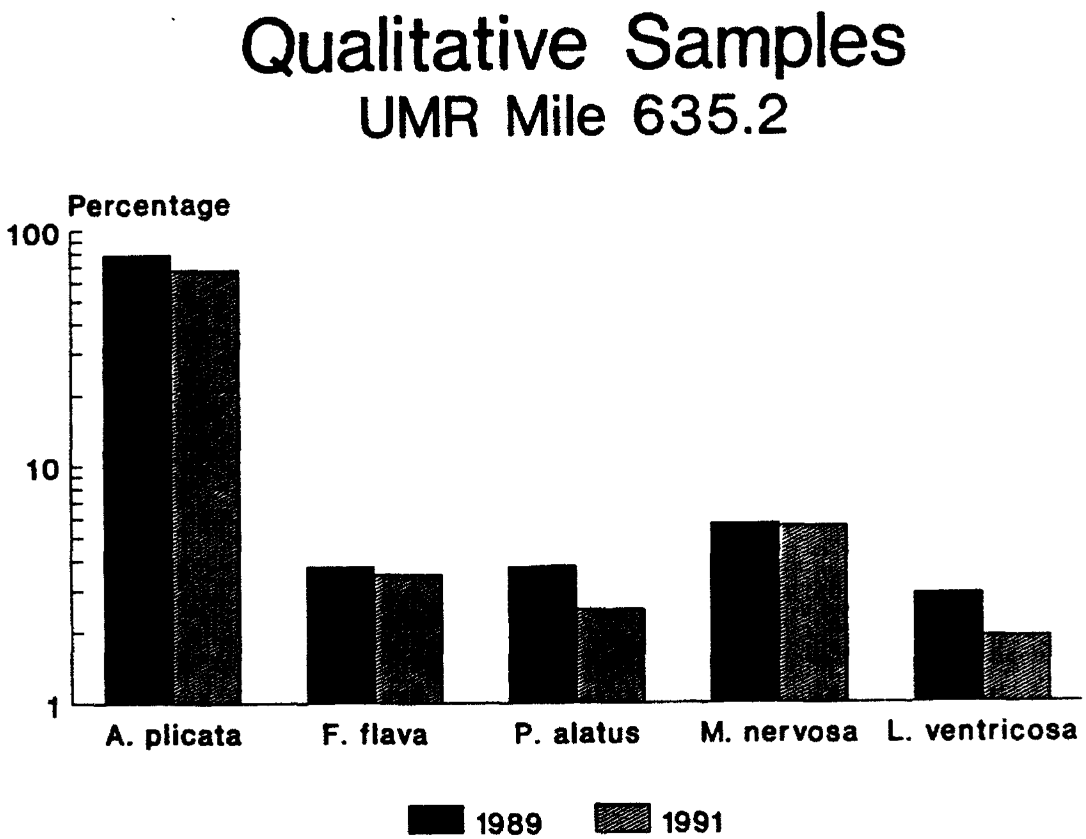
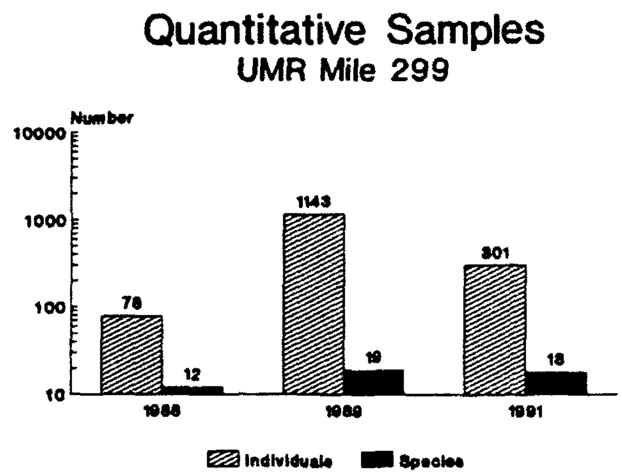


Figure 19. Percentage abundance of dominant species in 1989 and 1991 in qualitative samples at RM 635.2 in the UMR, 1991

Evidence of
recent recruitment

73. The percentage of all mussels and of all mussel species was variable at RM 299 (Figure 23). A comparatively high percentage of recent recruits was found in 1989 but not in 1988 or 1991. The number of species with representatives less than 30 mm declined slightly during the 3 study years. Less variability in recruitment was found at RM 504. Percentages of adults and individuals with representatives less than 30 mm total SL was slightly less in 1991 than the previous years. The percentage of small individuals at RM 635.2 was slightly less in 1991 than in 1989 (Figure 24). However, the total number of species collected and species diversity and evenness were relatively similar during the 2 study years.



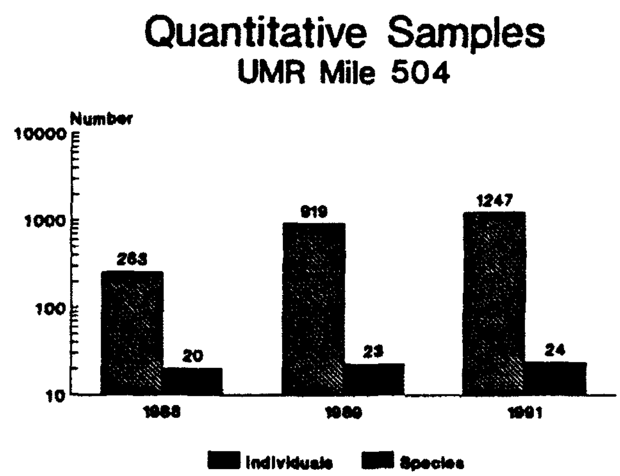
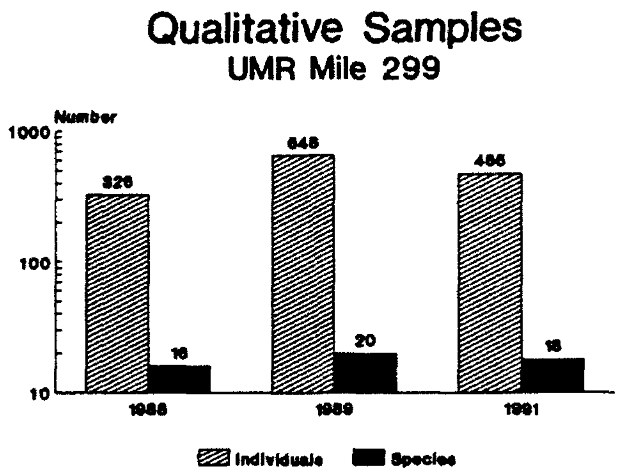


Figure 20. Percentage abundance of dominant species in 1988, 1989, and 1991 in quantitative samples at RM 299 and 504 in UMR, 1991

A significant change in growth
rates or mortality of dominant species

74. Size demography data can now be analyzed for three relatively abundant species, *A. plicata*, *O. reflexa*, and *T. truncata*, in Pool 14 based on data collected in 1988, 1989, and 1991. The three episodes of July sampling in this pool spanning a 4-year period clearly demonstrate the value of long-term monitoring of mussel beds.

75. Size demography of *A. p. plicata* in 1991 (Figure 25) indicated 3 consecutive years of strong recent recruitment (the three peaks centered at 18, 28, and 38 mm in length), preceded by approximately 3 years of weak



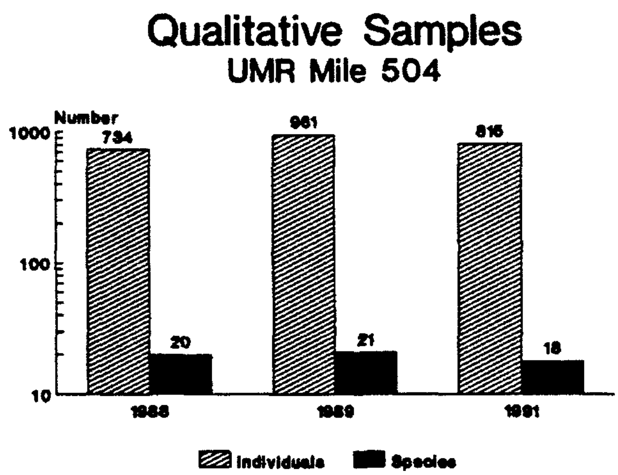
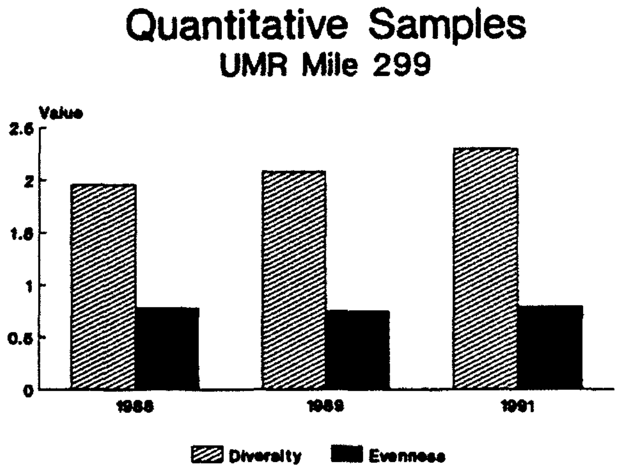


Figure 21. Number of individuals and species in qualitative samples collected in 1988, 1989, and 1991 at RM 299 and 504 in the UMR, 1991

recruitment (the valley from 45 to 65 mm). Prior to this, there were several years of generally strong recruitment (the abundance of mussels ranging from 70 to 90 mm in length). In 1989, this population showed only one strong recent year class, the 1989 cohort. In 1988, recent recruits were not evident. (The 1987 cohort was probably still too small to be sampled in July 1988). In 1988, there was a paucity of mussels less than 50 mm in length, indicating several years (perhaps 1986 through 1984) of weak recruitment. These years of low recruitment were apparent in the size frequency distribution as a "valley" ranging from 30 to 60 mm in 1989 and 45 to 65 mm in 1991



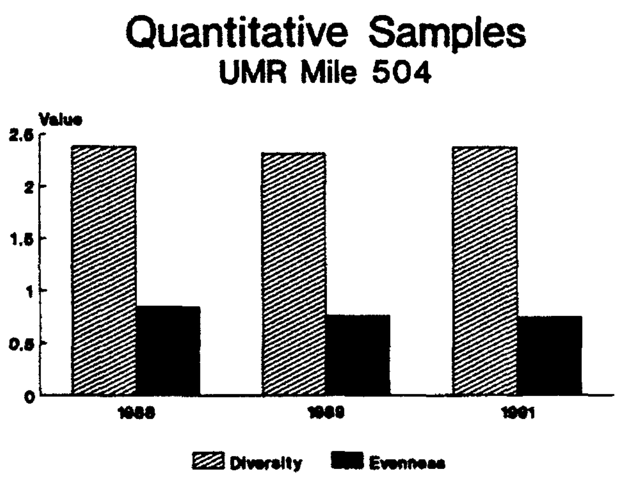
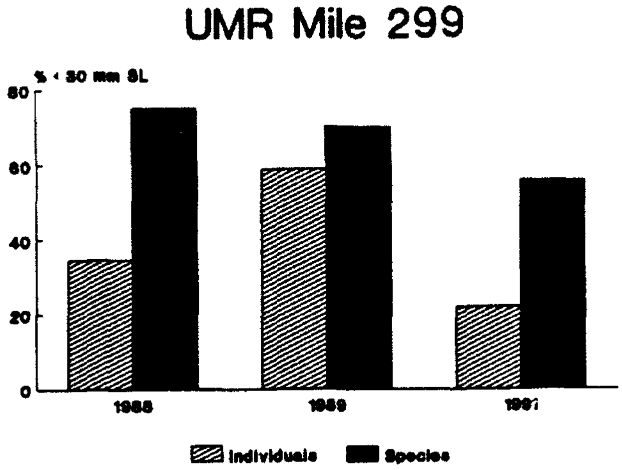


Figure 22. Species diversity and evenness quantitative samples collected in 1988, 1989, and 1991 at RM 632 in the UMR, 1991

(Figure 25). Occasional periods of low recruitment are common in long-lived species such as *A. p. plicata*. One interpretation of the 1988 results, when hardly any recent recruits to the *A. p. plicata* population were found, might have been to predict a population facing future decline because of poor recruitment conditions. However, subsequent sampling in 1989 and 1991 indicated a return to strong recruitment and an expected pattern of annual inconsistency in recruitment of long-lived mussel species.



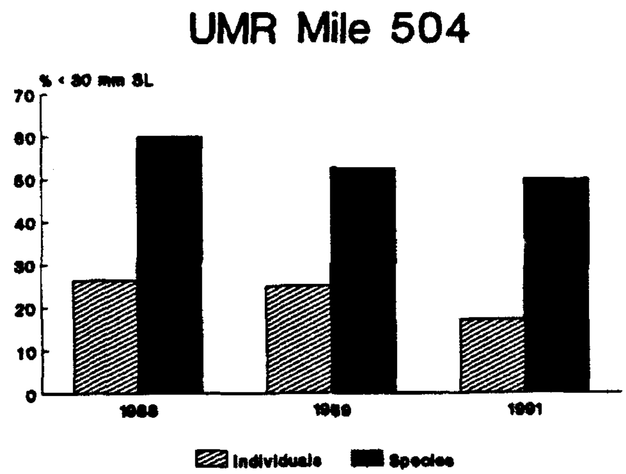


Figure 23. Percentage of individuals and species less than 30 mm total shell length taken in qualitative samples collected in 1988, 1989, and 1991 at RM 299 and 504 in the UMR, 1991

76. The size demography of *O. reflexa*, a moderately large mussel of intermediate longevity, generally showed three or four cohorts in 1988, 1989, and 1991 (Figure 26). Although a single mussel as large as 93 mm in length was obtained in 1988, the general paucity of mussels greater than 50 mm reflects a life span of approximately 4 to 5 years for most individuals in this population. This population exhibited annual inconsistency in recruitment strength. For example, the strength of the 19[illegible] cohort relative to the 1987 cohort was apparent in 1988, and this difference was sustained in 1989.

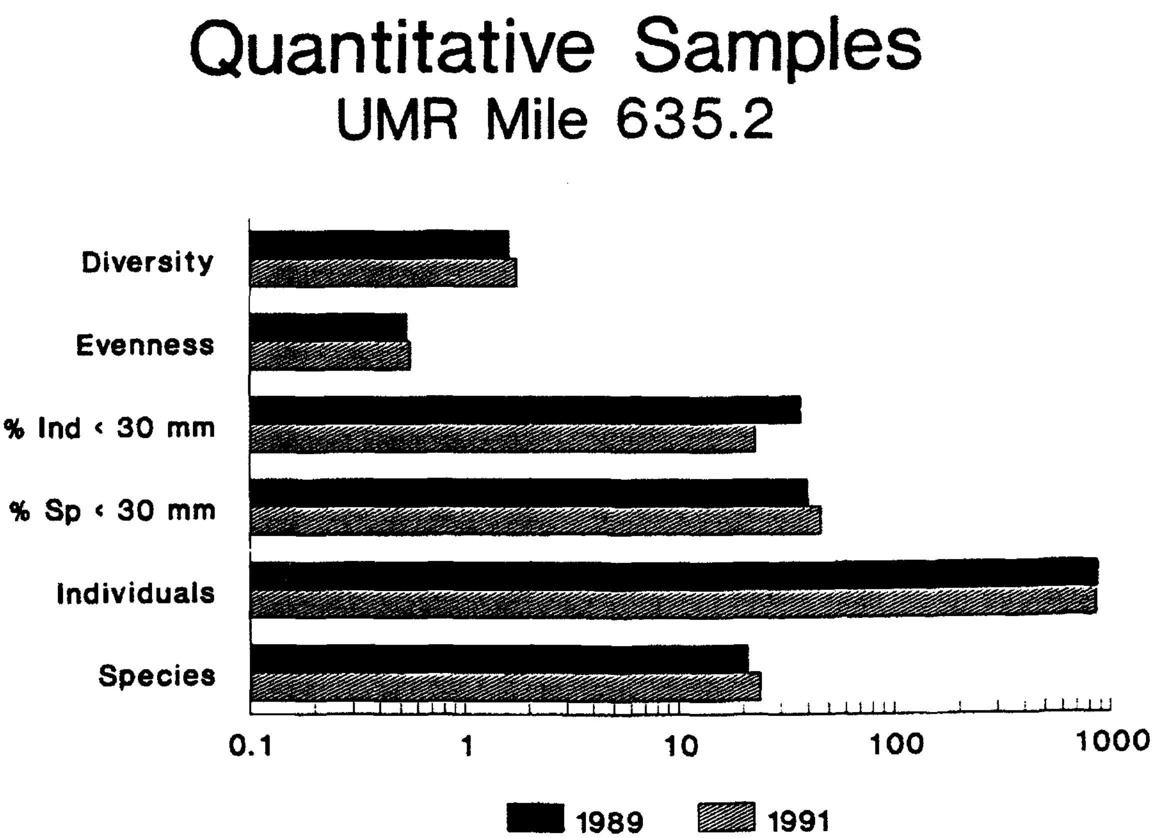


Figure 24. A comparison of diversity, evenness, recruitment strength, number of individuals, and species in quantitative samples collected at RM 635.2 in the UMR, 1991

A growth curve for this species based on year class assignments as suggested in Figure 26 is presented in Figure 27.

77. *Truncilla truncata* is smaller and slightly shorter-lived than *O. reflexa*. Three cohorts were always discerned in this population (Figure 28) and suggested a life span of approximately 3 years. The low relative abundance of the largest cohort (> 40 mm in length) in all July 1988, 1989, and 1991 indicates that few if any mussels survive through their fourth summer. A growth curve for this species based on year class assignments in Figure 28 is presented in Figure 27.

78. There were few differences in growth at nearshore and farshore sites for *O. reflexa* and *O. olivaria* collected in Pool 14 (Figure 29). These data are based on growth studies initiated in 1990. Future monitoring of growth, either from enclosure studies or from shell ring measurements, will be used to assess the possible effects of vessel traffic.

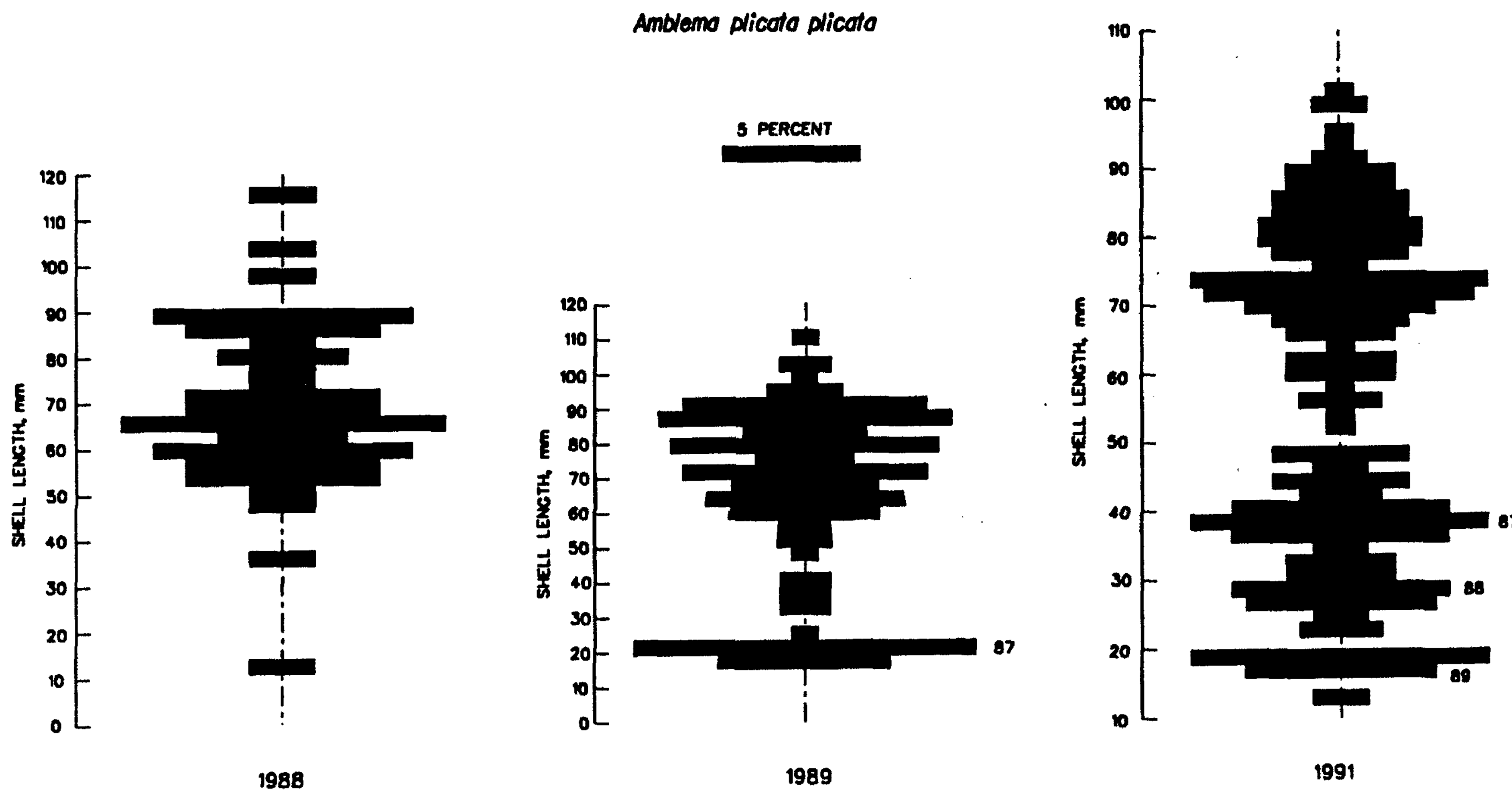


Figure 25. Size demography of *Amblema pl'cata plicata*, 1988, 1989, and 1991 near RM 504, Pool 14, UMR

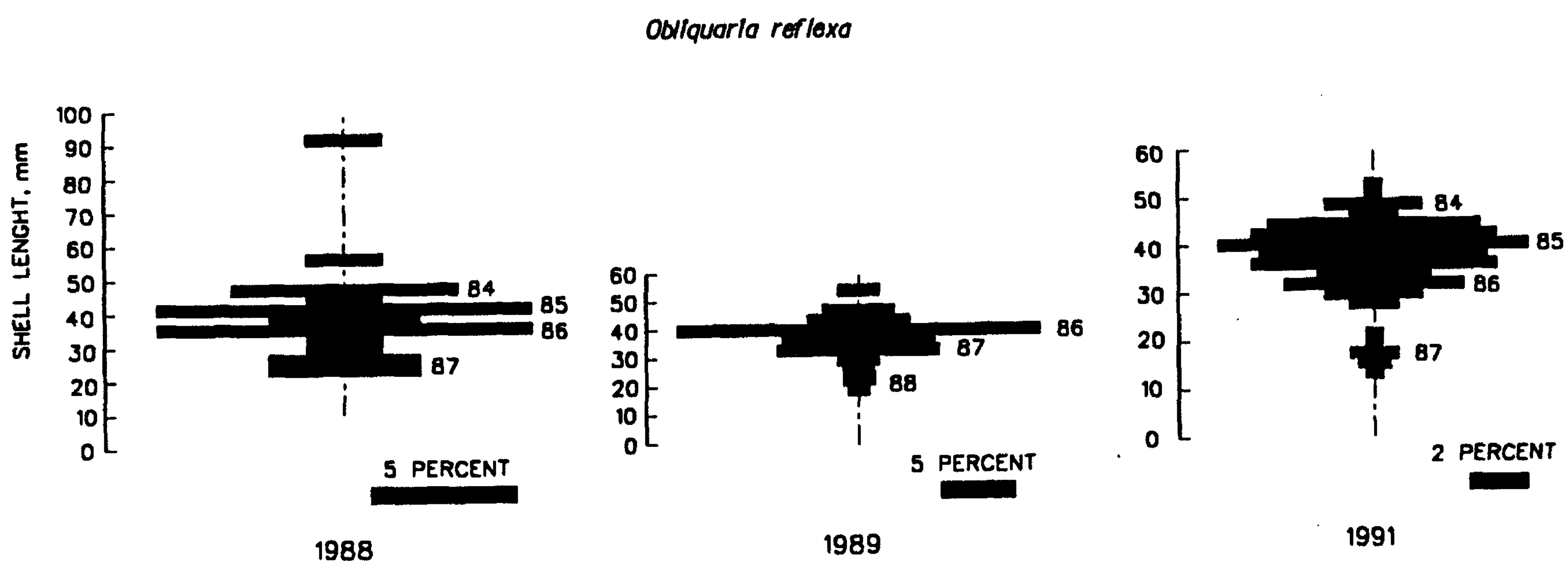
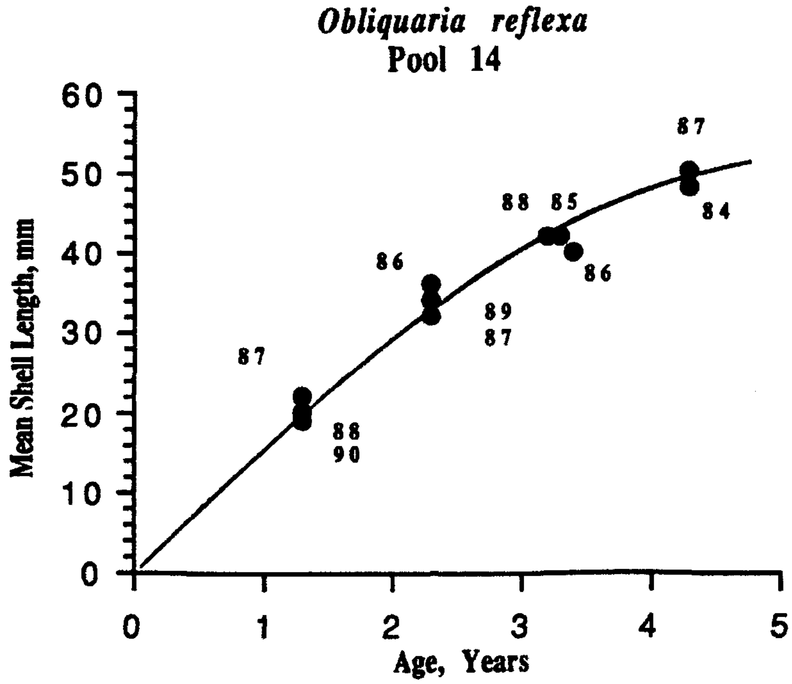


Figure 26. Size demography of *Obliquaria reflexa*, 1988, 1989, and 1991 near RM 504, Pool 14, UMR



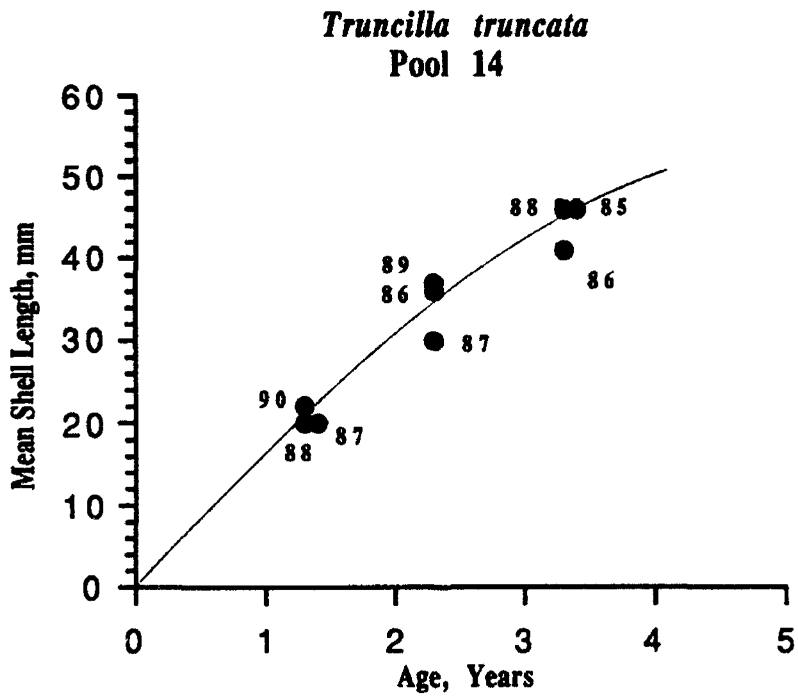


Figure 27. Growth rates of *Truncilla truncata* and *Obliquaria reflexa* near RM 504, Pool 14, based on size demography data (Numbers indicate assumed year class)

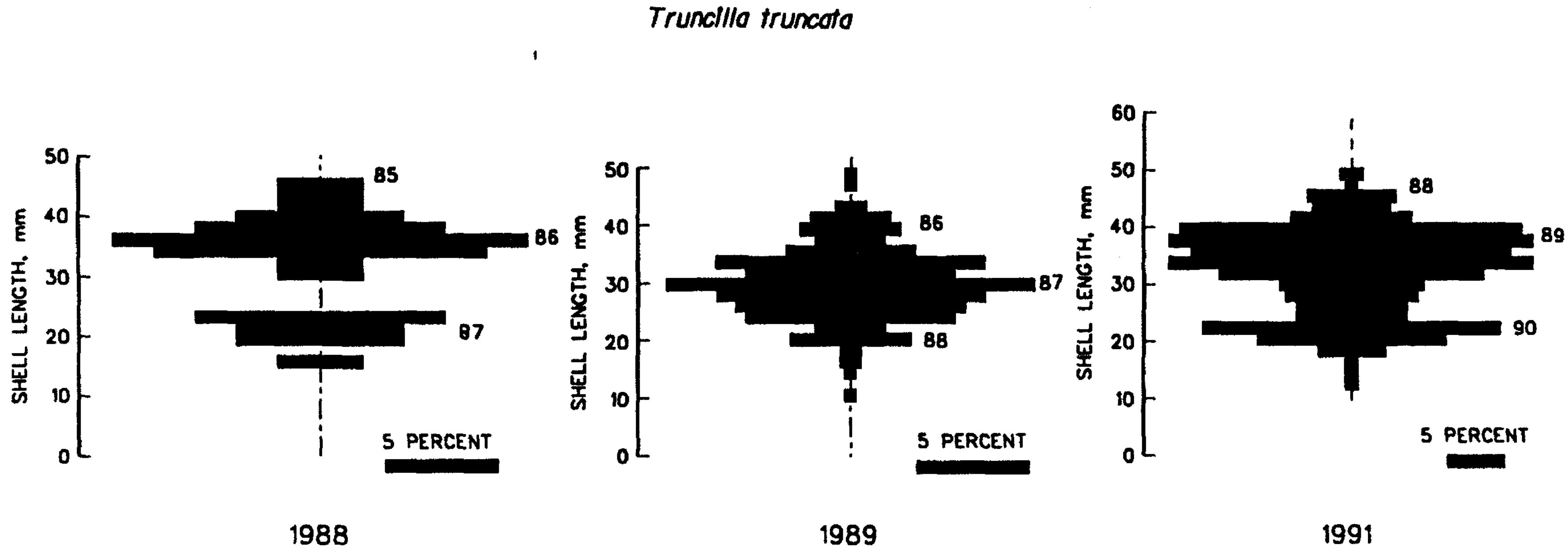
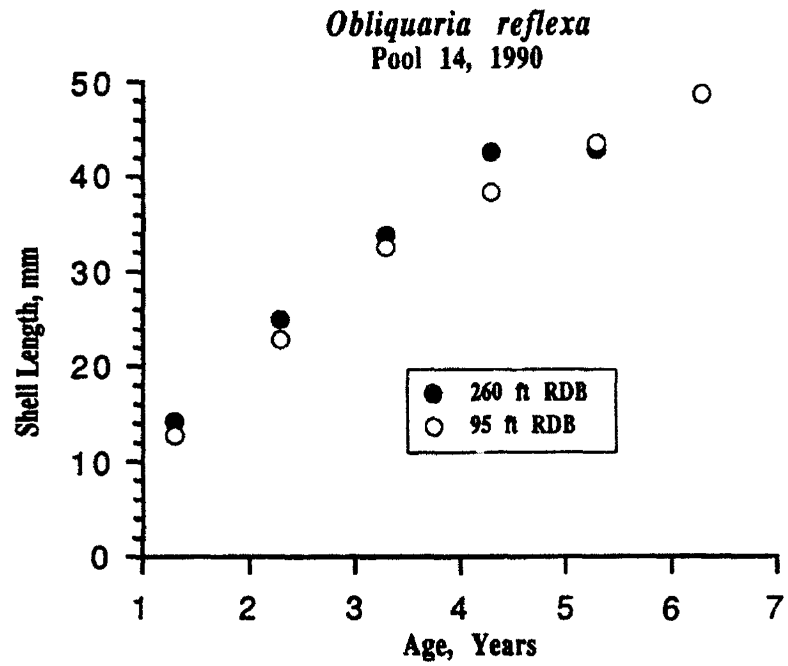


Figure 28. Size demography of *Truncilla truncata*, 1988, 1989, and 1991 near RM 504, Pool 14, UMR



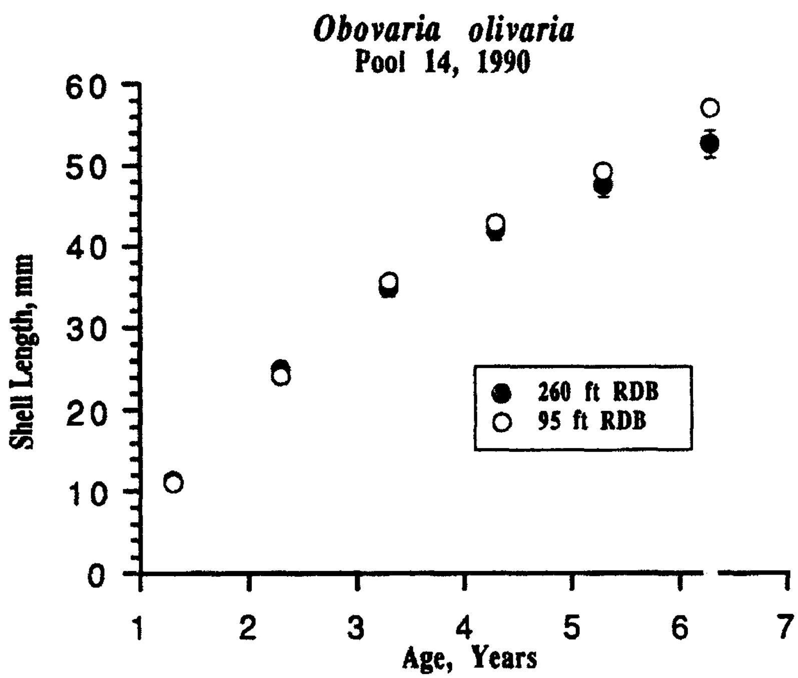


Figure 29. Growth rates of *Obliquaria reflexa* and *Obovaria olivaria* at nearshore and far-shore sites near RM 504, Pool 14, UMR, based on shell ring counts

Summary

79. Much has been published on the effects of commercial navigation traffic in the last 10 to 15 years and has appeared mostly in the government or nonrefereed literature (Virginia Polytechnic Institute and State University 1975; Academy of Natural Sciences of Philadelphia 1980; Berger Associates, Ltd. 1980; Sparks, Thomas, and Schaeffer 1980; US Army Corps of Engineers 1980; Lubinski et al. 1980, 1981; Environmental Science and Engineering 1981, 1988; Kennedy, Harber, and Littlejohn 1982; Rasmussen 1983; Simons et al. 1981; Simons, Ghaboosi, and Chang 1987; Wuebben, Brown, and Zabilansky 1984; and Nielsen, Sheehan, and Orth 1986). Wright (1982) reviewed these papers and considered most to be speculative. Regardless, the increasing use of inland waterways to transport bulk commodities (Dietz et al. 1983), and the recent articles on impacts of waterway use in Europe (Brookes and Hanbury 1990; Haendel and Tittizer 1990) illustrate that this is still an important issue.

80. The pulse of velocity and turbulence associated with vessel passage is usually considered to be the major detrimental effect of commercial traffic. It has been suggested that vessel-induced change in magnitude and direction of flow negatively affects benthic organisms by scouring substrates and resuspending fine-grained sediments. Tolerances of many aquatic organisms to sustained, specific levels of turbulence, water velocity, or suspended solids is known either from laboratory or field studies. Intermittent disturbances caused by vessel movement, pulses of suspended sediments, changes in water velocity, and periods of desiccation, can be simulated in the laboratory. Navigation-related laboratory studies have been conducted on fish eggs (Morgan et al. 1976), fish larvae (Killgore, Miller, and Conley 1987; Holland 1986; Payne, Killgore, and Miller 1991), plankton (Stevenson et al. 1986), and freshwater mussels (Aldridge, Payne, and Miller 1987; Payne and Miller 1987). Results of most studies demonstrated that mortality or physiological stress could be measured under conditions corresponding to high traffic intensity. In the field, discharge, flow patterns, bathymetry, and sediment characteristics have complex influences on vessel-induced disturbances. It is extremely difficult to estimate an organismal response to these intermittent physical effects, and it is even more difficult to accurately predict long-term responses of natural populations to such disturbances. Results of the few navigation-related field studies that have been conducted are characterized by extreme spatial and temporal variability so that clear patterns of

navigation effects often cannot be discerned (Sparks, Thomas, and Schaeffer 1980; Bhowmik et al. 1981a, 1981b; Seagle and Zumwalt 1981; Eckblad 1981; Eckblad, Volden, and Weilgart 1984; Environmental Science and Engineering, Inc. 1981). In addition, natural climatic and hydrologic conditions often overwhelm navigation effects (Johnson 1976).

81. An examination of the six attributes of a mussel bed that define its health or well-being were made based on studies conducted in the UMR since 1989. In most cases, 3 full years of comparison were made. An examination of these six attributes reveals that they are stable at these mussel beds. Future studies will be needed to determine if important indices such as rate of growth, density, species richness and diversity, etc., continue to remain stable. A detailed examination of physical effects of traffic at the sites where biological information is being collected is necessary to thoroughly evaluate effects of commercial traffic. Planners and resource managers are encouraged to make careful evaluations using these data rather than speculation based on "best estimates" or qualitative assessments such as habitat-based methods.

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Table 1

Summary of Biological and Physical Studies Conducted in the Navigation Traffic Effects Study, UMR, 1988-94

Pool	RM	Fiscal Year 88	89	90	91	92	93	94
24	299	Qual Quant	Qual Quant		Qual Quant Growth---------- Physical		Qual Quant	
17	450	Qual Quant		Qual Quant Growth---------- Physical		Qual Quant		Qual Quant
14	504	Qual Quant	Qual Quant Growth---------- Physical		Qual Quant Physical		Qual Quant	
12	571	Qual		Qual Quant Growth---------- Physical		Qual Quant		Qual Quant
10 (MC)	635	Qual	Qual Quant Growth---------- Physical		Quant Qual Physical		Quant Qual	

Notes: Quant - quantitative samples.
Qual - qualitative samples.
Growth - marked mussels are placed for analysis of rate of growth.
Physical - measures of water velocity and total suspended solids following passage of a commercial vessel.
MC - main channel.

Precise river miles are not given on this table since exact sample site location varies slightly (0.1 to 0.4 mile) each year.

Table 2

Quantitative and Qualitative Mussel Collections in the UMR, 1991

River Mile	Subsite	Distance to shore, ft	Depth ft	Qualitative Samples	Quantitative Samples
		8-11 July 1991, Pool 24			
299.6R	1	110	14	12	--
299.6R	2	50	12	12	--
299.6R	3	200	20	12	--
299.6R	1-3	100	11	--	30
299.6R	4-6	200	12	--	30
		13-16 July 1991, Pool 14			
504.8L	1-3	160	14	--	30
504.8L	4-6	300	14	--	30
504.8L	1	120	10	12	--
504.8L	2	180	13	12	--
504.8L	3	75	7	12	--
504.8L	4	350	20	12	--
		19-20 July 1991, Pool 10			
635.2R	1-3	75	11	--	30
635.2R	4-6	180	17	--	30
635.2R	1	50	14	12	--
635.2R	2	135	18	12	--
635.2R	3	160	18	12	--
635.2R	4	175	20	12	--

Table 3

Relative Abundance and Frequency of Occurrence of Freshwater Mussels Collected Using Qualitative Techniques in the UMR, July 1991

Species	Individuals	%	Samples	%
Amblema plicata plicata (Say 1817)	808	41.02	125	94.70
Quadrula pustulosa (Lea 1831)	172	8.73	64	48.48
Megalonaias nervosa (Rafinesque 1820)	152	7.72	75	56.82
Quadrula quadrula (Rafinesque 1820)	146	7.41	73	55.30
Ellipsaria lineolata (Rafinesque 1820)	113	5.74	43	32.58
Obliquaria reflexa (Rafinesque 1820)	107	5.43	55	41.67
Truncilla truncata (Lea 1860)	107	5.43	55	41.67
Fusconaia flava (Rafinesque 1820)	82	4.16	52	39.39
Leptodea fragilis (Rafinesque 1820)	59	2.99	42	31.82
Lampsilis ventricosa (Barnes 1823)	45	2.28	38	28.79
Obovaria olivaria (Rafinesque 1820)	43	2.18	32	24.24
Potamilus alatus (Say 1817)	31	1 57	28	21.21
Anodonta grandis (Say 1829)	17	0.86	14	10.61
Quadrula metanevra (Rafinesque 1820)	16	0.81	14	10.61
Strophitus undulatus (Say 1817)	14	0.71	14	10.61
Lampsilis higginsi (Lea 1857)	14	0.71	13	9.85
Ligumia recta (Lamarck 1819)	13	0.66	12	9.09
Elliptio dilatata (Rafinesque 1820)	10	0.51	10	7.58
Quadrula nodulata (Rafinesque 1817)	9	0.46	9	6.82
Arcidens confragosus (Say 1829)	8	0.41	8	6.06
Actinonaias ligamentina (Lamarck 1819)	1	0.05	1	0.76
Lasmigona complanata (Barnes 1823)	1	0.05	1	0.76
Anodonta imbecillis (Say 1829)	1	0.05	1	0.76
Lampsilis radiata (Gmelin 1791)	1	0.05	1	0.76

Total individuals	1,970
Total species	23
Total samples	132

Note: Samples were collected at mussel beds in Pool 24 (RM 299.6), Pool 14 (RM 504.8), and Pool 10 (RM 635.2).

Table 4

Summary Statistics for Unionids (Average Density and Standard Error (SE)) Collected in 0.25 m^2 Quadrats at RM 299.6R, Pool 24, UMR, 1991

Subsite	Distance to shore, ft	Density	SE
1	100	4.4	1.62
2	100	8.0	2.59
3	100	2.8	0.85
Total	100	5.1	1.10
1	200	42.8	8.92
2	200	34.0	4.63
3	200	28.4	3.12
Total	200	35.1	3.56

Analysis of Variance (between sites):

F	PR>F*
64.8	0.0001

* Probability of a greater F value.

Table 5

Summary Statistics for Unionids (Average Density and Standard Error (SE))

Collected in 0.25 m^2 Quadrats at RM 504.8R, Pool 14, UMR, 1991

Subsite	Distance to shore, ft	Density	SE
1	160	93.6	7.23
2	160	92.8	7.03
3	160	68.0	11.17
Total	160	84.8	5.36
1	300	84.4	9.24
2	300	73.2	5.72
3	300	86.8	18.87
Total	300	81.4	4.13

Analysis of Variance (between sites):

F	PR>F*
0.24	0.624

* Probability of a greater F value.

Table 6

Summary Statistics for Unionids (Average Density and Standard Error (SE))

Collected in 0.25 m^2 Quadrats at RM 635.2, Pool 10, UMR, 1991

Subsite	Distance to shore, ft	Density	SE
1	75	70.0	6.54
2	75	61.6	5.59
3	75	56.4	5.92
Total	75	62.7	3.52
1	180	42.0	5.13
2	180	52.4	3.06
3	180	62.0	6.59
Total	180	52.1	3.24

Analysis of Variance (between sites):

F	PR>F*
4.85	0.0316

* Probability of a greater F value.

Table 7

Total Number and Percent *Lampsilis higginsi* Taken in Qualitative and Quantitative Samples in the UMR, 1988-91

Location	Quantitative			Qualitative		
	Total Mussels	*L. higginsi* Total	%	Total Mussels	*L. higginsi* Total	%
Pool 24 (RM 299)						
1988	78	-	--	326	-	--
1989	1143	-	--	648	-	--
1990	--	-	--	--	-	--
1991	301	-	--	465	-	--
Pool 17 (RM 450)						
1988	--	-	--	567	1	0.18
1990	--	-	--	--	-	--
Pool 12 (RM 570)						
1989	--	-	--	98	-	--
1990	408	5	1.22	518	5	0.98
Pool 14 (RM 505)						
1988	253	1	0.40	734	8	1.09
1989	1131	1	0.09	961	5	0.52
1991	1247	3	0.24	815	10	1.23
Pool 10 (RM 635)						
1988	845	2	0.24	699	12	1.72
1989	1616	11	0.68	212	0	--
1991	861	2	0.23	690	4	0.58

Note: More precise river miles cannot be given since there were variations of 0.1 to 0.4 miles each year.

Table 8

Number of Fresh Dead Mussels (Tissue Present) in Quantitative Samples Collected at RM 299.6, 504.8, and 635.2, UMR, July 1991

Location	Subsite 1	Subsite 2	Subsite 3
RM 299.6			
100 ft from RDB	0	0	0
200 ft from RDB	1	0	0
RM 504.8			
160 ft from LDB	1	0	2
300 ft from LDB	1	0	0
RM 635.2			
75 ft from RDB	1	0	2
180 ft from RDB	0	0	0

Table 9

Physical Information Pertaining to Vessel Passage, UMR, July 1991*

Date July	Event No.	Test No.	River Mile	Vessel Name	Config (lxw)	Total Barges	Vessel Cond	Vessel Dist	Vessel Direction
8	1	1	299.4R	Carole Brent	1x2+1	3	Unloaded	675	Upriver
8	2	2	299.4R	Rusty Flowers	5x3+1	16	Unloaded	700	Upriver
8	3	3	299.4R	Hornet Jenco	5x3	15	Loaded	950	Downriver
8	4	4	299.4R	J. W. Hershey	4x3	12	Loaded	950	Downriver
8	1	5	299.4R	Sir Randy J	2x2	4	Loaded	950	Downriver
8	2	6	299.4R	Cooperative Venture	5x3	15	Unloaded	520	Upriver
8	3	7	299.4R	Sunflower	5x3	15	Loaded	--	Downriver
8	4	8	299.4R	Christina Eckstein	5x3-1	14	Unloaded	825	Upriver
8	5	9	299.4R	Marvin E. Norman	5x3	15	Unloaded	--	Upriver
10	1	10	299.4R	Jemco Towing Inc.	5x3	15	Loaded	850	Downriver
10	2	11	299.4R	Irving Crown	2x3	6	Loaded	850	Downriver
10	3	12	299.4R	Creole Bell	5x3	15	NA	1000	NA
10	4	13	299.4R	Little_ _	1x2	2	Loaded	1000	Downriver
10	5	14	299.4R	Dell Butcher	5x3	15	Loaded	1000	Upriver
13	1	15	504.7L	Dell Butcher	3x4	12	Loaded	750	Upriver
13	2	16	504.7L	Ambient	--	--	--	--	--
13	3	17	504.7L	Christina Eckstine	4x3	12	Loaded	750	Downriver
14	1	18	504.7L	Quad City Queen	--	--	--	400	Upriver
14	2	19	504.7L	Ambient	--	--	--	--	--
15	1	20	504.7L	Eastern	4x3	12	Loaded	650	Downriver
15	2	21	504.7L	Volunteer State	5x3-1	14	Unloaded	750	Upriver
15	3	22	504.7L	BVEY-T	3x2-1	5	Unloaded	1000	Upriver
15	4	23	504.7L	Ambient	--	--	--	--	--
16	1	24	504.7L	Scarlet Knight	5x3	15	Loaded	1000	Downriver
16	2	25	504.7L	Dub Hollinger	4x3	12	Loaded	1000	Downriver
16	3	26	504.7L	James F. Neal	5x3	15	Loaded	750	Downriver
16	4	27	504.7L	Janet L. Kusak	5x3	15	Loaded	750	Downriver
16	5	28	504.7L	Ambient	--	--	--	--	--
16	6	29	504.7L	NA	2x2	4	NA	NA	Upriver

(Continued)

* All distances are in feet.

Table 9 (Continued)

Test No.	Real Time: Start	Real Time: Front of tow Passes	Real Time: End of tow Passes	Real Time: Stop	Time from Start: Tow Front Passes	Time from Start: Tow End Passes	No. Barges	Total Len ft	Sec to pass	ft/sec	mi/hr
1	101930	102013	102114	103100	44	105	2	370	61	6.07	4.14
2	111730	111834	112122	112540	64	233	6	1110	169	6.57	4.48
3	160720	160703	160840	161410	0	81	5	925	81	11.42	7.79
4	174930	175143	175276	175800	123	166	4	740	43	17.21	11.73
5	115020	115249	115323	120020	150	184	2	370	34	10.88	7.42
6	131230	132303	133752	135000	631	1520	5	925	889	1.04	0.71
7	13300	135129	135256	135620	1290	1377	5	925	87	10.63	7.25
8	143550	144113	144428	145240	324	519	5	925	195	4.74	3.23
9	160000	160540	160809	161600	341	490	5	925	149	6.21	4.23
10	110830	111025	111143	112100	46	194	5	925	148	6.25	4.26
11	121120	121340	121417	122010	141	178	2	370	37	10.00	6.82
12	134710	134910	135026	135630	121	197	5	925	76	12.17	8.30
13	141200	141314	141354	141810	75	115	?	0	40	0.00	0.00
14	150640	151040	151250	152800	241	371	5	925	130	7.12	4.85
15	135830	140013	140201	141000	104	212	4	740	108	6.85	4.67
16	151640	--	--	152800	--	--	--	--	--	--	--
17	160230	160410	160535	161250	101	186	4	740	85	8.71	5.94
18	113840	114448	--	115500	1369	--	--	--	--	--	--
19	161810	--	--	163540	--	--	--	--	--	--	--
20	91010	912100	91234	92050	121	145	4	740	24	30.83	21.02
21	102810	103003	103155	103530	114	226	5	925	112	8.26	5.63
22	105330	105938	105533	110500	69	124	3	555	55	10.09	6.88
23	150710	--	--	151940	--	--	--	--	--	--	--
24	90700	912200	91355	91913	131	226	5	925	95	9.74	6.64
25	103100	103421	103556	104106	202	297	4	740	95	7.79	5.31
26	120330	120619	120744	121510	170	255	5	925	85	10.88	7.42
27	142500	142857	143049	143750	238	350	5	925	112	8.26	5.63
28	155340	--	--	160200	--	--	--	--	--	--	--
29	160530	160939	161009	161400	250	280	2	370	30	12.33	8.41

(Continued)

Note: Total barge length = 185 ft.

(Sheet 2 of 3)

Table 9 (Concluded)

Test	Sensor 942			Sensor 946			Sensor 939			Sensor 940			Nixon Sensor		
No.	Code	Dist	Dep	Code	Dist	Dep	Code	Dist	Dep	Code	Dist	Dep	Dist.	Water Dep	Dist to Substrate
1	A1	50	7	A2	100	7	B3	150	14	B4	200	17	--	1'2"	4"
2	A1	50	7	A2	100	7	B3	150	14	B4	200	17	--	1'2"	4"
3	A1	50	7	A2	100	7	B3	150	14	B4	200	17	5'10"	1'4"	6"
4	A1	50	7	A2	100	7	B3	150	14	B4	200	17	5'10"	1'4"	6"
5	A1	50	5	A2-Tri	50	5	B3	100	10	B4	100	10	--	--	--
6	A1	50	5	A2-Tri	50	5	B3	100	10	B4	100	10	--	--	--
7	A1	50	5	A2-Tri	50	5	B3	100	10	B4	100	10	--	--	--
8	A1	50	5	A2-Tri	50	5	B3	100	10	B4	100	10	--	--	--
9	A1	50	5	A2-Tri	50	5	B3	100	10	B4	100	10	--	--	--
10	--	--	--	--	--	--	B3	50	5	B4	150	14	--	--	--
11	--	--	--	--	--	--	B3	50	5	B4	150	14	--	--	--
12	--	--	--	--	--	--	B3	50	5	B4	150	14	--	--	--
13	--	--	--	--	--	--	B3	50	5	B4	150	14	--	--	--
14	--	--	--	--	--	--	B3	50	5	B4	150	14	--	--	--
15	--	--	--	A1	16	2'8"	--	--	--	--	--	--	14	2'4"	2"
16	--	--	--	A1	16	2'8"	--	--	--	--	--	--	14	2'4"	2"
17	--	--	--	A1	16	2'8"	--	--	--	--	--	--	14	2'4"	2"
18	A1	80	6	A2-Tri	80	6	B3	200	14	B4	400	20	14	2'4"	2"
19	A1	80	6	A2-Tri	80	6	B3	200	14	B4	400	20	14	2'4"	2"
20	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
21	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
22	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
23	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
24	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
25	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
26	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
27	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
28	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"
29	--	--	--	--	--	--	B3	200	14	B4-T	200	14	14	2'4"	2"

Note: The four sensors refer to the Model 527 current velocity meter.
The Nixon water velocity probe is a small mechanical sensor (probe diameter of 11 mm) that was used to measure water velocity near the substrate water interface.
The term "Tri" refers to placing the sensor on a tripod so that velocity could be measured near the substrate water interface.
"Dist" is the distance from the shore in feet.
"Dep" is water depth where the (Marsh McBirney) sensor was placed. The Nixon sensor was 2 to 6 in. above the substrate water interface.

APPENDIX A: FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR) IN 1991 USING QUALITATIVE TECHNIQUES

Table A1

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 229.6, Pool 24, July 1991

Species	Site 1	Site 2	Site 3	Total
A. p. plicata	28.38	27.33	19.16	24.73
M. nervosa	5.41	10.00	37.72	18.49
E. lineolata	12.84	20.00	13.17	15.27
O. reflexa	16.22	12.67	3.59	10.54
Q. quadrula	6.76	8.67	4.19	6.45
Q. pustulosa	6.76	4.67	4.19	5.16
T. truncata	6.76	2.67	4.79	4.73
F. flava	8.78	4.00	1.20	4.52
L. ventricosa	1.35	0.67	4.19	2.15
O. olivaria	1.35	2.67	2.40	2.15
L. fragilis	2.03	3.33	0.00	1.72
A. grandis	0.68	0.67	2.99	1.51
Q. nodulata	0.68	0.67	0.60	0.65
Q. metanevra	0.00	1.33	0.60	0.65
P. alatus	0.00	0.67	0.60	0.43
A. confragosus	0.68	0.00	0.60	0.43
L. recta	0.68	0.00	0.00	0.22
L. complanata	0.68	0.00	0.00	0.22
Total individuals	148	150	167	465
Total species				18
Species diversity				2.23
Evenness				0.77
Dominance				0.14

Note: See Table 2 for more information on location of sites.

Table A2

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 504.8, Pool 14, July 1991

Species	Site 1	Site 2	Site 3	Site 4	Total
A. p. plicata	22.97	20.87	43.78	25.71	28.10
Q. pustulosa	20.57	24.35	11.44	12.00	17.55
Q. quadrula	8.61	6.52	6.97	15.43	9.08
T. truncata	11.48	9.57	5.97	6.29	8.47
O. reflexa	17.22	5.65	5.47	5.14	8.47
M. nervosa	4.31	9.57	3.48	2.86	5.28
F. flava	2.87	3.48	5.97	6.29	4.54
O. olivaria	1.91	6.09	1.99	4.57	3.68
L. fragilis	1.44	2.17	3.48	8.00	3.56
E. lineolata	1.44	3.48	2.99	5.71	3.31
L. ventricosa	2.87	3.04	2.99	1.71	2.70
P. alatus	1.44	1.30	1.99	1.14	1.47
L. higginsi	1.44	0.87	1.00	1.71	1.23
Q. metanevra	0.48	0.87	0.50	1.14	0.74
L. recta	0.00	0.00	1.49	1.14	0.61
Q. nodulata	0.48	1.30	0.00	0.00	0.49
A. grandis	0.48	0.43	0.50	0.00	0.37
A. confragosus	0.00	0.43	0.00	1.14	0.37
Total individuals	209	230	201	175	815
Total species					18
Species diversity					2.29
Evenness					0.79
Dominance					0.14

Note: See Table 2 for more information on location of sites.

Table A3

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at UMR Mile 635.2, Pool 10, July 1991

Species	Site 1	Site 2	Site 3	Site 4	Total
A. p. plicata	61.67	65.09	72.33	70.33	67.25
M. nervosa	8.33	8.28	4.40	1.10	5.51
F. flava	4.44	2.37	3.14	3.85	3.48
L. fragilis	3.89	4.73	3.14	1.65	3.33
Q. quadrula	1.67	4.14	4.40	3.30	3.33
P. alatus	2.78	3.55	1.89	1.65	2.46
S. undulatus	2.78	2.37	1.26	1.65	2.03
T. truncata	2.78	0.59	2.52	2.20	2.03
L. ventricosa	2.78	3.55	0.00	1.10	1.88
E. dilatata	1.67	1.78	1.26	1.10	1.45
O. reflexa	1.11	0.00	1.89	1.65	1.16
L. recta	1.67	0.59	1.26	0.55	1.01
Q. metanevra	0.00	0.00	1.26	2.75	1.01
Q. pustulosa	1.11	0.00	0.00	2.75	1.01
A. grandis	1.11	0.59	0.63	1.10	0.87
L. higginsi	0.00	1.18	0.00	1.10	0.58
A. confragosus	1.11	0.59	0.00	0.00	0.43
O. olivaria	0.00	0.59	0.00	1.10	0.43
Q. nodulata	0.00	0.00	0.00	1.10	0.29
A. imbecillis	0.56	0.00	0.00	0.00	0.14
A. ligamentina	0.56	0.00	0.00	0.00	0.14
L. siliquoidea	0.00	0.00	0.63	0.00	0.14
Total individuals	180	169	159	182	690
Total species					22
Species diversity					1.51
Evenness					0.49
Dominance					0.46

Note: See Table 2 for more information on location of sites.

Table A4

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at River Mile (RM) 299.6, Pool 24, July 1991

Species	Site 1	Site 2	Site 3	Total
A. p. plicata	100.00	75.00	91.67	88.89
E. lineolata	75.00	83.33	75.00	77.78
M. nervosa	41.67	50.00	100.00	63.89
Q. quadrula	66.67	58.33	50.00	58.33
O. reflexa	66.67	75.00	25.00	55.56
T. truncata	66.67	25.00	41.67	44.44
Q. pustulosa	50.00	41.67	33.33	41.67
F. flava	50.00	33.33	16.67	33.33
O. olivaria	16.67	25.00	33.33	25.00
L. ventricosa	8.33	8.33	41.67	19.44
A. grandis	8.33	8.33	41.67	19.44
L. fragilis	25.00	25.00	0.00	16.67
Q. nodulata	8.33	8.33	8.33	8.33
Q. metanevra	0.00	16.67	8.33	8.33
P. alatus	0.00	8.33	8.33	5.56
A. confragosus	8.33	0.00	8.33	5.56
L. recta	8.33	0.00	0.00	2.78
L. complanata	8.33	0.00	0.00	2.78
Total samples	12	12	12	36

Note: See Table 2 for more information on location of sites.

Table A5

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at RM 504.8, Pool 14, July 1991

Species	Site 1	2	3	4	Total
A. p. plicata	91.67	100.00	100.00	100.00	93.75
Q. pustulosa	100.00	91.67	75.00	75.00	87.50
Q. quadrula	75.00	66.67	66.67	66.67	75.00
T. truncata	66.67	50.00	50.00	50.00	56.25
O. reflexa	83.33	50.00	41.67	41.67	56.25
M. nervosa	58.33	58.33	50.00	50.00	50.00
F. flava	41.67	58.33	41.67	41.67	50.00
O. olivaria	33.33	58.33	33.33	33.33	45.83
E. lineolata	25.00	50.00	41.67	41.67	41.67
L. fragilis	25.00	33.33	33.33	33.33	39.58
L. ventricosa	50.00	41.67	41.67	41.67	37.50
P. alatus	25.00	25.00	33.33	33.33	25.00
L. higginsi	25.00	16.67	8.33	8.33	18.75
Q. metanevra	8.33	8.33	8.33	8.33	10.42
L. recta	0.00	0.00	25.00	25.00	10.42
Q. nodulata	8.33	25.00	0.00	0.00	8.33
A. grandis	8.33	8.33	8.33	8.33	6.25
A. confragosus	0.00	8.33	0.00	0.00	6.25
Total samples	12	12	12	12	48

Note: See Table 2 for more information on location of sites.

Table A6

Frequency of Occurrence of Freshwater Bivalves Collected Using Qualitative Techniques at RM 635.2, Pool 10, July 1991

Species	Site 1	Site 2	Site 3	Site 4	Total
A. p. plicata	100.00	100.00	100.00	100.00	100.00
M. nervosa	66.67	66.67	41.67	16.67	47.92
Q. quadrula	16.67	41.67	50.00	33.33	35.42
L. fragilis	50.00	25.00	33.33	25.00	33.33
F. flava	50.00	16.67	33.33	33.33	33.33
S. undulatus	41.67	33.33	16.67	25.00	29.17
P. alatus	33.33	41.67	25.00	16.67	29.17
T. truncata	41.67	8.33	25.00	33.33	27.08
L. ventricosa	33.33	41.67	0.00	16.67	22.92
E. dilatata	25.00	25.00	16.67	16.67	20.83
O. reflexa	16.67	0.00	25.00	16.67	14.58
Q. pustulosa	16.67	0.00	0.00	33.33	12.50
Q. metanevra	0.00	0.00	16.67	33.33	12.50
L. recta	25.00	8.33	8.33	8.33	12.50
A. grandis	16.67	8.33	8.33	8.33	10.42
L. higginsi	0.00	16.67	0.00	16.67	8.33
O. olivaria	0.00	8.33	0.00	16.67	6.25
A. confragosus	16.67	8.33	0.00	0.00	6.25
Q. nodulata	0.00	0.00	0.00	16.67	4.17
L. siliquoidea	0.00	0.00	8.33	0.00	2.08
A. ligamentina	8.33	0.00	0.00	0.00	2.08
A. imbecillis	8.33	0.00	0.00	0.00	2.08
Total samples	12	12	12	12	48

Note: See Table 2 for more information on location of sites.

APPENDIX B: FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR), JULY 1991, USING QUANTITATIVE TECHNIQUES

Table B1

Relative Species Abundances Data Collected at Distances of 100 and 200 ft from the Right Descending Bank, Pool 24, River Mile (RM) 299.6, July 9, 1991

Species	Nearshore	Farshore	Total
A. p. plicata	26.32	21.29	25.10
E. lineolata	0.00	23.95	23.95
O. reflexa	21.05	11.79	14.83
T. truncata	10.53	12.93	14.45
C. fluminea	21.05	5.32	8.37
M. nervosa	0.00	6.08	6.08
Q. pustulosa	5.26	2.66	3.42
Q. quadrula	7.89	2.28	3.42
O. olivaria	0.00	3.04	3.04
F. flava	5.26	1.52	2.28
L. fragilis	0.00	2.28	2.28
T. donaciformis	0.00	1.52	1.52
L. recta	0.00	1.14	1.14
L. ventricosa	2.63	0.76	1.14
P. alatus	0.00	1.14	1.14
Q. metanevra	0.00	1.14	1.14
A. imbecillis	0.00	0.76	0.76
F. ebena	0.00	0.38	0.38
Total individuals	38	263	301
Total species	8	18	18
Total quadrats	30	30	60
Species diversity	1.85	2.26	2.29
Evenness	0.89	0.78	0.79
Dominance	0.16	0.14	0.13
Individuals <30 mm SL	44.7%	18.6%	21.9%
Species <30 mm	62.5%	44.4%	55.5%

Note: Each site consists of three closely spaced subsites where ten quantitative samples were collected (see Table 2).

Table B2

Relative Species Abundances Data Collected at Distances of 160 and 300 ft from the Right Descending Bank, Pool 14, RM 504.8, July 1991

Species	Nearshore	Farshore	Total
T. truncata	20.91	23.57	22.21
Q. pustulosa	17.14	15.06	16.12
A. p. plicata	15.57	14.57	15.08
O. reflexa	11.01	8.51	9.78
Q. quadrula	8.96	9.00	8.98
F. flava	4.56	5.89	5.21
E. lineolata	3.77	4.42	4.09
L. fragilis	3.77	4.26	4.01
O. olivaria	3.46	4.42	3.93
M. nervosa	3.46	3.11	3.29
T. donaciformis	1.26	1.80	1.52
L. ventricosa	1.89	0.82	1.36
L. recta	0.63	0.82	0.72
A. imbecillis	0.63	0.65	0.64
P. alatus	0.47	0.49	0.48
A. confragosus	0.63	0.33	0.48
L. complanata	0.31	0.49	0.40
Q. nodulata	0.47	0.33	0.40
Q. metanevra	0.47	0.33	0.40
A. grandis	0.16	0.33	0.24
L. higginsi	0.16	0.33	0.24
S. undulatus	0.16	0.16	0.16
E. dilatata	0.00	0.33	0.16
C. fluminea	0.16	0.00	0.08
Total individuals	636	611	1247
Total species	23	23	24
Total quadrats	30	30	60
Species diversity	2.36	2.38	2.37
Evenness	0.75	0.76	0.75
Dominance	0.12	0.12	0.12
Individuals <30 mm SL	17.3%	17.0%	17.2%
Species <30 mm	43.5%	39.1%	50.0%

Note: Each site consists of three closely spaced subsites where ten quantitative samples were collected (see Table 2).

Table B3

Relative Species Abundances Data Collected at Distances of 75 and 180 ft from the Right Descending Bank, Pool 10, RM 635.2, July 1991

Species	Nearshore	Farshore	Total
A. p. plicata	57.66	53.20	56.09
T. truncata	14.04	14.58	14.40
M. nervosa	3.62	4.35	3.98
L. fragilis	3.83	3.84	3.86
O. reflexa	2.77	3.84	3.28
P. alatus	1.91	4.09	2.93
F. flava	2.98	2.30	2.69
E. dilatata	1.28	3.07	2.11
L. ventricosa	1.49	2.05	1.76
Q. pustulosa	2.13	0.26	1.29
T. donaciformis	0.85	1.79	1.29
Q. quadrula	1.06	1.02	1.05
A. grandis	0.85	0.77	0.82
S. undulatus	0.85	0.77	0.82
A. confragosus	1.06	0.00	0.59
A. imbecillis	2.55	0.51	1.66
L. recta	0.00	1.79	0.81
Q. nodulata	0.21	0.51	0.35
T. parvus	0.00	0.77	0.35
L. higginsi	0.21	0.26	0.23
E. lineolata	0.21	0.00	0.12
O. olivaria	0.21	0.00	0.12
A. ligamentina	0.00	0.26	0.12
Q. metanevra	0.21	0.00	0.12
Total individuals	470	391	861
Total species	21	20	24
Total quadrats	30	30	60
Species diversity	1.69	1.81	1.77
Eveness	0.56	0.60	0.56
Dominance	0.36	0.31	0.34
Individuals <30 mm SL	20.0%	26.1%	22.8%
Species <30 mm	33.3%	45.0%	45.8%

Note: Each site consists of three closely spaced subsites where ten quantitative samples were collected (see Table 2).

APPENDIX C: LENGTH-FREQUENCY HISTOGRAMS FOR BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR), 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
12		0	0	0.00	0.00
14	**	1	1	1.52	1.52
16		0	1	0.00	1.52
18	***	2	3	3.03	4.55
20	**	1	4	1.52	6.06
22		0	4	0.00	6.06
24		0	4	0.00	6.06
26	**	1	5	1.52	7.58
28	********************	13	18	19.70	27.27
30	********	5	23	7.58	34.85
32	*********	6	29	9.09	43.94
34	*********	6	35	9.09	53.03
36		0	35	0.00	53.03
38	***	2	37	3.03	56.06
40	**	1	38	1.52	57.58
42		0	38	0.00	57.58
44	***	2	40	3.03	60.61
46	***	2	42	3.03	63.64
48	**	1	43	1.52	65.15
50	***	2	45	3.03	68.18
52		0	45	0.00	68.18
54		0	45	0.00	68.18
56	**	1	46	1.52	69.70
58	**	1	47	1.52	71.21
60		0	47	0.00	71.21
62		0	47	0.00	71.21
64		0	47	0.00	71.21
66	**	1	48	1.52	72.73
68		0	48	0.00	72.73
70		0	48	0.00	72.73
72		0	48	0.00	72.73
74		0	48	0.00	72.73
76		0	48	0.00	72.73
78	**	1	49	1.52	74.24
80		0	49	0.00	74.24
82	**	1	50	1.52	75.76
84	**	1	51	1.52	77.27
86		0	51	0.00	77.27
88		0	51	0.00	77.27
90	***	2	53	3.03	80.30
92	******	4	57	6.06	86.36
94		0	57	0.00	86.36
96	***	2	59	3.03	89.39
98	***	2	61	3.03	92.42
100	**	1	62	1.52	93.94
102	**	1	63	1.52	95.45
104	***	2	65	3.03	98.48
106		0	65	0.00	98.48
108		0	65	0.00	98.48
110		0	65	0.00	98.48
112		0	65	0.00	98.48
114		0	65	0.00	98.48
116	**	1	66	1.52	100.00
118		0	66	0.00	100.00
120		0	66	0.00	100.00
122		0	66	0.00	100.00
124		0	66	0.00	100.00
126		0	66	0.00	100.00

-----+----+----+----+
5 10 15 20

Percentage

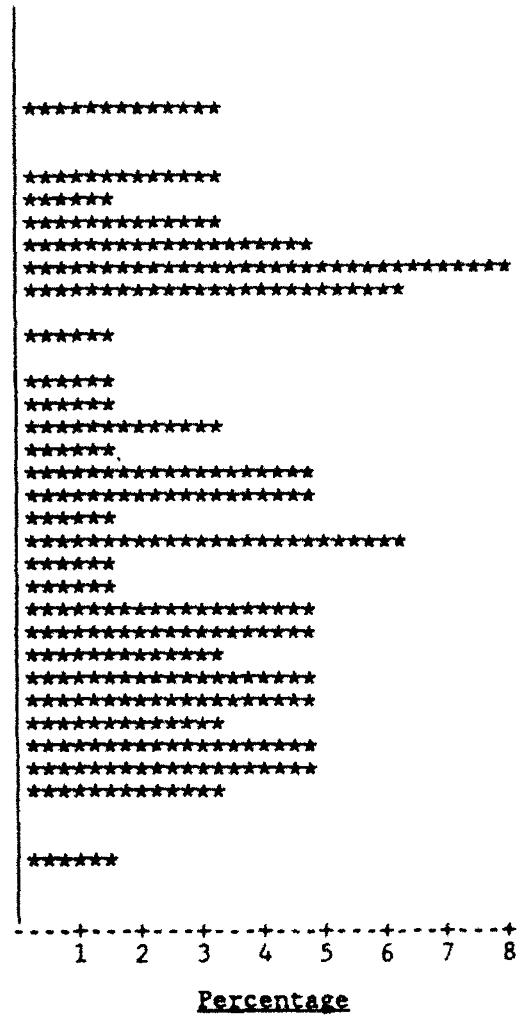
Figure C1. Shell length (mm) frequency histogram of *Amblema plicata plicata* in the upper Mississippi River, river mile (RM) 299.6 (Pool 24), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
6		0	0	0.00	0.00
8	**	1	1	4.55	4.55
10	*******	3	4	13.64	18.18
12	************************************	16	20	72.73	90.91
14	*****	2	22	9.09	100.00
16		0	22	0.00	100.00
18		0	22	0.00	100.00
20		0	22	0.00	100.00
22		0	22	0.00	100.00
24		0	22	0.00	100.00
26		0	22	0.00	100.00
28		0	22	0.00	100.00

10 20 30 40 50 60 70

<u>Percentage</u>

Figure C2. Shell length (mm) frequency histogram of *Corbicula fluminea* in the upper Mississippi River, RM 299.6 (Pool 24), nearshore and farshore sites combined, July 1991



Shell Length	Freq	Cumulative Freq	Percent	Cumulative Percent
22	0	0	0.00	0.00
24	0	0	0.00	0.00
26	0	0	0.00	0.00
28	0	0	0.00	0.00
30	2	2	3.17	3.17
32	0	2	0.00	3.17
34	0	2	0.00	3.17
36	2	4	3.17	6.35
38	1	5	1.59	7.94
40	2	7	3.17	11.11
42	3	10	4.76	15.87
44	5	15	7.94	23.81
46	4	19	6.35	30.16
48	0	19	0.00	30.16
50	1	20	1.59	31.75
52	0	20	0.00	31.75
54	1	21	1.59	33.33
56	1	22	1.59	34.92
58	2	24	3.17	38.10
60	1	25	1.59	39.68
62	3	28	4.76	44.44
64	3	31	4.76	49.21
66	1	32	1.59	50.79
68	4	36	6.35	57.14
70	1	37	1.59	58.73
72	1	38	1.59	60.32
74	3	41	4.76	65.08
76	3	44	4.76	69.84
78	2	46	3.17	73.02
80	3	49	4.76	77.78
82	3	52	4.76	82.54
84	2	54	3.17	85.71
86	3	57	4.76	90.48
88	3	60	4.76	95.24
90	2	62	3.17	98.41
92	0	62	0.00	98.41
94	0	62	0.00	98.41
96	1	63	1.59	100.00
98	0	63	0.00	100.00
100	0	63	0.00	100.00

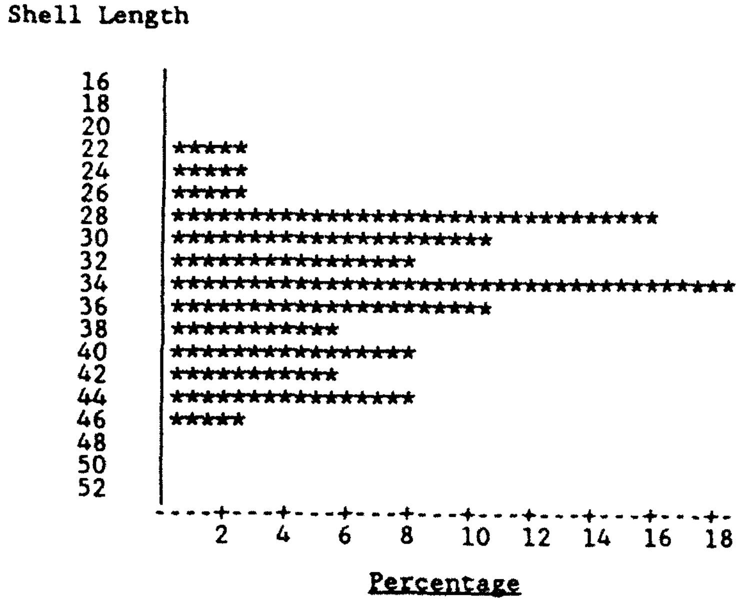
Figure C3. Shell length (mm) frequency histogram of *Ellipsaria lineolata* in the upper Mississippi River, RM 299.6 (Pool 24), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
12		0	0	0.00	0.00
14	***	1	1	2.56	2.56
16		0	1	0.00	2.56
18		0	1	0.00	2.56
20		0	1	0.00	2.56
22		0	1	0.00	2.56
24		0	1	0.00	2.56
26		0	1	0.00	2.56
28		0	1	0.00	2.56
30	********	3	4	7.69	10.26
32	***	1	5	2.56	12.82
34	*****	2	7	5.13	17.95
36	*************	5	12	12.82	30.77
38	*****	2	14	5.13	35.90
40	*********************	8	22	20.51	56.41
42	**************************	10	32	25.64	82.05
44	*****	2	34	5.13	87.18
46	***	1	35	2.56	89.74
48	********	3	38	7.69	97.44
50		0	38	0.00	97.44
52		0	38	0.00	97.44
54	***	1	39	2.56	100.00
56		0	39	0.00	100.00
58		0	39	0.00	100.00
60		0	39	0.00	100.00
62		0	39	0.00	100.00
64		0	39	0.00	100.00

5 10 15 20 25

Percentage

Figure C4. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 299.6 (Pool 24), nearshore and farshore sites combined, July 1991



Shell Length	Freq	Cumulative Freq	Percent	Cumulative Percent
16	0	0	0.00	0.00
18	0	0	0.00	0.00
20	0	0	0.00	0.00
22	1	1	2.63	2.63
24	1	2	2.63	5.26
26	1	3	2.63	7.89
28	6	9	15.79	23.68
30	4	13	10.53	34.21
32	3	16	7.89	42.11
34	7	23	18.42	60.53
36	4	27	10.53	71.05
38	2	29	5.26	76.32
40	3	32	7.89	84.21
42	2	34	5.26	89.47
44	3	37	7.89	97.37
46	1	38	2.63	100.00
48	0	38	0.00	100.00
50	0	38	0.00	100.00
52	0	38	0.00	100.00

Figure C5. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299.6 (Pool 24), nearshore and farshore sites combined, July 1991

```
Shell Length                                          Cumulative  Cumulative
                                                 Freq  Freq  Percent  Percent

  10 |                                               0     0    0.00     0.00
  12 |*****                                          2     2    1.06     1.06
  14 |                                               0     2    0.00     1.06
  16 |*******************                            7     9    3.72     4.79
  18 |*****************************                 11    20    5.85    10.64
  20 |                                               0    20    0.00    10.64
  22 |********                                       3    23    1.60    12.23
  24 |*****                                          2    25    1.06    13.30
  26 |*******************                            7    32    3.72    17.02
  28 |*********************                          8    40    4.26    21.28
  30 |***********                                    4    44    2.13    23.40
  32 |***********                                    4    48    2.13    25.53
  34 |*****                                          2    50    1.06    26.60
  36 |*********************                          8    58    4.26    30.85
  38 |*****************************                 11    69    5.85    36.70
  40 |*********************                          8    77    4.26    40.96
  42 |********                                       3    80    1.60    42.55
  44 |*************                                  5    85    2.66    45.21
  46 |*****                                          2    87    1.06    46.28
  48 |*************                                  5    92    2.66    48.94
  50 |                                               0    92    0.00    48.94
  52 |***                                            1    93    0.53    49.47
  54 |***                                            1    94    0.53    50.00
  56 |********                                       3    97    1.60    51.60
  58 |***                                            1    98    0.53    52.13
  60 |***********                                    4   102    2.13    54.26
  62 |***********                                    4   106    2.13    56.38
  64 |***                                            1   107    0.53    56.91
  66 |***********                                    4   111    2.13    59.04
  68 |*************                                  5   116    2.66    61.70
  70 |*******************                            7   123    3.72    65.43
  72 |***************************                   10   133    5.32    70.74
  74 |*****************************                 11   144    5.85    76.60
  76 |*****                                          2   146    1.06    77.66
  78 |*************                                  5   151    2.66    80.32
  80 |****************                               6   157    3.19    83.51
  82 |****************                               6   163    3.19    86.70
  84 |*************                                  5   168    2.66    89.36
  86 |*************                                  5   173    2.66    92.02
  88 |***********                                    4   177    2.13    94.15
  90 |***********                                    4   181    2.13    96.28
  92 |*****                                          2   183    1.06    97.34
  94 |***                                            1   184    0.53    97.87
  96 |***                                            1   185    0.53    98.40
  98 |                                               0   185    0.00    98.40
 100 |*****                                          2   187    1.06    99.47
 102 |***                                            1   188    0.53   100.00
 104 |                                               0   188    0.00   100.00
 106 |                                               0   188    0.00   100.00
 108 |                                               0   188    0.00   100.00
 110 |                                               0   188    0.00   100.00
      -----+----+----+----+----+----
           1    2    3    4    5

              Percentage
```

Figure C6. Shell length (mm) frequency histogram of *Amblema plicata plicata* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
10		0	0	0.00	0.00
12	****	1	1	1.96	1.96
14	****	1	2	1.96	3.92
16		0	2	0.00	3.92
18		0	2	0.00	3.92
20	****	1	3	1.96	5.88
22		0	3	0.00	5.88
24		0	3	0.00	5.88
26		0	3	0.00	5.88
28		0	3	0.00	5.88
30		0	3	0.00	5.88
32	****************	4	7	7.84	13.73
34	************	3	10	5.88	19.61
36	************	3	13	5.88	25.49
38	********	2	15	3.92	29.41
40	************	3	18	5.88	35.29
42	****	1	19	1.96	37.25
44	********	2	21	3.92	41.18
46	********	2	23	3.92	45.10
48	********	2	25	3.92	49.02
50	********	2	27	3.92	52.94
52	********************	5	32	9.80	62.75
54	********	2	34	3.92	66.67
56	************	3	37	5.88	72.55
58	****************	4	41	7.84	80.39
60	****	1	42	1.96	82.35
62	********	2	44	3.92	86.27
64	********	2	46	3.92	90.20
66	********	2	48	3.92	94.12
68		0	48	0.00	94.12
70		0	48	0.00	94.12
72	****	1	49	1.96	96.08
74		0	49	0.00	96.08
76		0	49	0.00	96.08
78	****	1	50	1.96	98.04
80		0	50	0.00	98.04
82		0	50	0.00	98.04
84	****	1	51	1.96	100.00
86		0	51	0.00	100.00
88		0	51	0.00	100.00
90		0	51	0.00	100.00
92		0	51	0.00	100.00
	----+---+---+---+---+				
	2 4 6 8 10				
	Percentage				

Figure C7. Shell length (mm) frequency histogram of *Ellipsaria lineolata* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
12		0	0	0.00	0.00
14		0	0	0.00	0.00
16	***	1	1	1.54	1.54
18		0	1	0.00	1.54
20		0	1	0.00	1.54
22		0	1	0.00	1.54
24		0	1	0.00	1.54
26	***	1	2	1.54	3.08
28		0	2	0.00	3.08
30	***	1	3	1.54	4.62
32	***	1	4	1.54	6.15
34		0	4	0.00	6.15
36	***	1	5	1.54	7.69
38	******	2	7	3.08	10.77
40	*********	3	10	4.62	15.38
42	******************************	10	20	15.38	30.77
44	************	4	24	6.15	36.92
46	******************	6	30	9.23	46.15
48	***	1	31	1.54	47.69
50	******	2	33	3.08	50.77
52	*********	3	36	4.62	55.38
54		0	36	0.00	55.38
56	*********	3	39	4.62	60.00
58	******	2	41	3.08	63.08
60	******************	6	47	9.23	72.31
62	************	4	51	6.15	78.46
64	*********	3	54	4.62	83.08
66	******	2	56	3.08	86.15
68	*********	3	59	4.62	90.77
70	******	2	61	3.08	93.85
72		0	61	0.00	93.85
74	*********	3	64	4.62	98.46
76	***	1	65	1.54	100.00
78		0	65	0.00	100.00
80		0	65	0.00	100.00
82		0	65	0.00	100.00
84		0	65	0.00	100.00
	2 4 6 8 10 12 14				
	Percentage				

Figure C8. Shell length (mm) frequency histogram of *Fusconaia flava* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

```
                                                    Cumulative      Cumulative
Shell Length                                  Freq   Freq  Percent   Percent

   30  |                                        0      0     0.00      0.00
   32  |****                                    1      1     2.00      2.00
   34  |********                                2      3     4.00      6.00
   36  |****                                    1      4     2.00      8.00
   38  |                                        0      4     0.00      8.00
   40  |********                                2      6     4.00     12.00
   42  |********                                2      8     4.00     16.00
   44  |****                                    1      9     2.00     18.00
   46  |********                                2     11     4.00     22.00
   48  |************                            3     14     6.00     28.00
   50  |************                            3     17     6.00     34.00
   52  |************                            3     20     6.00     40.00
   54  |********                                2     22     4.00     44.00
   56  |********************************        8     30    16.00     60.00
   58  |****                                    1     31     2.00     62.00
   60  |****************                        4     35     8.00     70.00
   62  |****                                    1     36     2.00     72.00
   64  |********                                2     38     4.00     76.00
   66  |                                        0     38     0.00     76.00
   68  |                                        0     38     0.00     76.00
   70  |                                        0     38     0.00     76.00
   72  |                                        0     38     0.00     76.00
   74  |****************                        4     42     8.00     84.00
   76  |********                                2     44     4.00     88.00
   78  |****                                    1     45     2.00     90.00
   80  |                                        0     45     0.00     90.00
   82  |                                        0     45     0.00     90.00
   84  |****                                    1     46     2.00     92.00
   86  |********                                2     48     4.00     96.00
   88  |                                        0     48     0.00     96.00
   90  |****                                    1     49     2.00     98.00
   92  |                                        0     49     0.00     98.00
   94  |****                                    1     50     2.00    100.00
   96  |                                        0     50     0.00    100.00
   98  |                                        0     50     0.00    100.00
  100  |                                        0     50     0.00    100.00
  102  |                                        0     50     0.00    100.00
  104  |                                        0     50     0.00    100.00
  106  |                                        0     50     0.00    100.00
  108  |                                        0     50     0.00    100.00
  110  |                                        0     50     0.00    100.00
       ----+---+---+---+---+---+---+---+
           2   4   6   8  10  12  14  16

                  Percentage
```

Figure C9. Shell length (mm) frequency histogram of *Leptodea fragilis* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
30		0	0	0.00	0.00
32	*****	1	1	2.44	2.44
34		0	1	0.00	2.44
36		0	1	0.00	2.44
38		0	1	0.00	2.44
40		0	1	0.00	2.44
42		0	1	0.00	2.44
44		0	1	0.00	2.44
46		0	1	0.00	2.44
48		0	1	0.00	2.44
50		0	1	0.00	2.44
52		0	1	0.00	2.44
54		0	1	0.00	2.44
56	*****	1	2	2.44	4.88
58	*****	1	3	2.44	7.32
60	*****	1	4	2.44	9.76
62		0	4	0.00	9.76
64		0	4	0.00	9.76
66		0	4	0.00	9.76
68		0	4	0.00	9.76
70	********************	4	8	9.76	19.51
72	***************	3	11	7.32	26.83
74	*****	1	12	2.44	29.27
76	**********	2	14	4.88	34.15
78	*****	1	15	2.44	36.59
80		0	15	0.00	36.59
82		0	15	0.00	36.59
84	**********	2	17	4.88	41.46
86		0	17	0.00	41.46
88	***************	3	20	7.32	48.78
90	***************	3	23	7.32	56.10
92		0	23	0.00	56.10
94		0	23	0.00	56.10
96		0	23	0.00	56.10
98		0	23	0.00	56.10
100		0	23	0.00	56.10
102	*****	1	24	2.44	58.54
104	*****	1	25	2.44	60.98
106		0	25	0.00	60.98
108	********************	4	29	9.76	70.73
110		0	29	0.00	70.73
112	***************	3	32	7.32	78.05
114	**********	2	34	4.88	82.93
116	**********	2	36	4.88	87.80
118	*****	1	37	2.44	90.24
120		0	37	0.00	90.24
122	*****	1	38	2.44	92.68
124		0	38	0.00	92.68
126		0	38	0.00	92.68
128	*****	1	39	2.44	95.12
130	*****	1	40	2.44	97.56
132		0	40	0.00	97.56
134		0	40	0.00	97.56
136		0	40	0.00	97.56
138	*****	1	41	2.44	100.00
140		0	41	0.00	100.00
142		0	41	0.00	100.00

----+---+---+---+---+
 2 4 6 8 10

Percentage

Figure C10. Shell length (mm) frequency histogram of *Megalonaias nervosa* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
14		0	0	0.00	0.00
16	**	1	1	0.82	0.82
18	***	2	3	1.64	2.46
20	*****	3	6	2.46	4.92
22	**	1	7	0.82	5.74
24	**	1	8	0.82	6.56
26		0	8	0.00	6.56
28		0	8	0.00	6.56
30	*****	3	11	2.46	9.02
32	**********	6	17	4.92	13.93
34	******************	11	28	9.02	22.95
36	***********	7	35	5.74	28.69
38	*************************	15	50	12.30	40.98
40	***********************	14	64	11.48	52.46
42	*******************************	19	83	15.57	68.03
44	*************************	15	98	12.30	80.33
46	*********************	13	111	10.66	90.98
48	*****	3	114	2.46	93.44
50	**********	6	120	4.92	98.36
52	**	1	121	0.82	99.18
54	**	1	122	0.82	100.00
56		0	122	0.00	100.00
58		0	122	0.00	100.00
60		0	122	0.00	100.00

----+---+---+---+---+---+---+---
2 4 6 8 10 12 14

Percentage

Figure C11. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites c -ned, July 1991

```
Shell Length                                                  Cumulative  Cumulative
                                                        Freq  Freq   Percent  Percent

 34  |                                                    0     0     0.00     0.00
 36  |****                                                1     1     2.04     2.04
 38  |****                                                1     2     2.04     4.08
 40  |****                                                1     3     2.04     6.12
 42  |********                                            2     5     4.08    10.20
 44  |********                                            2     7     4.08    14.29
 46  |************                                        3    10     6.12    20.41
 48  |********                                            2    12     4.08    24.49
 50  |************************                            6    18    12.24    36.73
 52  |************************                            6    24    12.24    48.98
 54  |************************************                9    33    18.37    67.35
 56  |************************                            6    39    12.24    79.59
 58  |********************                                5    44    10.20    89.80
 60  |****************                                    4    48     8.16    97.96
 62  |****                                                1    49     2.04   100.00
 64  |                                                    0    49     0.00   100.00
 66  |                                                    0    49     0.00   100.00
 68  |                                                    0    49     0.00   100.00
 70  |                                                    0    49     0.00   100.00
 72  |                                                    0    49     0.00   100.00
 74  |                                                    0    49     0.00   100.00
     ----+---+---+---+---+---+---+---+---+-
         2   4   6   8  10  12  14  16  18

              Percentage
```

Figure C12. Shell length (mm) frequency histogram of *Obovaria olivaria* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
6		0	0	0.00	0.00
8	****	2	2	1.00	1.00
10	******	3	5	1.49	2.49
12	************	6	11	2.99	5.47
14	**	1	12	0.50	5.97
16	********	4	16	1.99	7.96
18	**********	5	21	2.49	10.45
20	****	2	23	1.00	11.44
22	**	1	24	0.50	11.94
24	**	1	25	0.50	12.44
26	****	2	27	1.00	13.43
28	**********	5	32	2.49	15.92
30	**************	7	39	3.48	19.40
32	****************	8	47	3.98	23.38
34	********************	10	57	4.98	28.36
36	****************	8	65	3.98	32.34
38	************************	12	77	5.97	38.31
40	****************	8	85	3.98	42.29
42	************************	12	97	5.97	48.26
44	******************************	15	112	7.46	55.72
46	**********************************	17	129	8.46	64.18
48	******************************	15	144	7.46	71.64
50	**********************************	17	161	8.46	80.10
52	************************************	18	179	8.96	89.05
54	********************	10	189	4.98	94.03
56	********	4	193	1.99	96.02
58	********	4	197	1.99	98.01
60	**	1	198	0.50	98.51
62	******	3	201	1.49	100.00
64		0	201	0.00	100.00
66		0	201	0.00	100.00
68		0	201	0.00	100.00
70		0	201	0.00	100.00

----+---+---+---+---+---+---+---+---+
1 2 3 4 5 6 7 8 9

Percentage

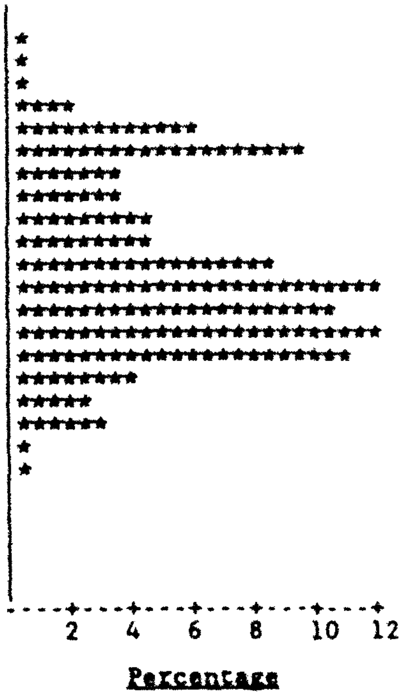
Figure C13. Shell length (mm) frequency histogram of *Quadrula pustulosa* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

```
Shell Length                                                  Cumulative  Cumulative
                                                        Freq  Freq  Percent  Percent

14 |                                                    0     0    0.00     0.00
16 |***********                                         3     3    2.68     2.68
18 |                                                    0     3    0.00     2.68
20 |**************                                      4     7    3.57     6.25
22 |*******                                             2     9    1.79     8.04
24 |****                                                1    10    0.89     8.93
26 |                                                    0    10    0.00     8.93
28 |                                                    0    10    0.00     8.93
30 |****                                                1    11    0.89     9.82
32 |***********                                         3    14    2.68    12.50
34 |***********                                         3    17    2.68    15.18
36 |*******                                             2    19    1.79    16.96
38 |******************                                  5    24    4.46    21.43
40 |*******                                             2    26    1.79    23.21
42 |*******                                             2    28    1.79    25.00
44 |***********                                         3    31    2.68    27.68
46 |****                                                1    32    0.89    28.57
48 |**************                                      4    36    3.57    32.14
50 |***********                                         3    39    2.68    34.82
52 |*********************                               6    45    5.36    40.18
54 |***********                                         3    48    2.68    42.86
56 |******************                                  5    53    4.46    47.32
58 |*************************                           7    60    6.25    53.57
60 |******************                                  5    65    4.46    58.04
62 |************************************               10    75    8.93    66.96
64 |*************************                           7    82    6.25    73.21
66 |*******                                             2    84    1.79    75.00
68 |*********************                               6    90    5.36    80.36
70 |**************                                      4    94    3.57    83.93
72 |*************************                           7   101    6.25    90.18
74 |***********                                         3   104    2.68    92.86
76 |**************                                      4   108    3.57    96.43
78 |****                                                1   109    0.89    97.32
80 |****                                                1   110    0.89    98.21
82 |****                                                1   111    0.89    99.11
84 |                                                    0   111    0.00    99.11
86 |****                                                1   112    0.89   100.00
88 |                                                    0   112    0.00   100.00
90 |                                                    0   112    0.00   100.00
   ----+---+---+---+---+---+---+---+---+
       1   2   3   4   5   6   7   8   9

              Percentage
```

Figure C14. Shell length (mm) frequency histogram of *Quadrula quadrula* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991



Shell Length	Freq	Cumulative Freq	Percent	Cumulative Percent
10	0	0	0.00	0.00
12	1	1	0.36	0.36
14	1	2	0.36	0.72
16	1	3	0.36	1.08
18	6	9	2.17	3.25
20	17	26	6.14	9.39
22	27	53	9.75	19.13
24	10	63	3.61	22.74
26	10	73	3.61	26.35
28	12	85	4.33	30.69
30	13	98	4.69	35.38
32	24	122	8.66	44.04
34	33	155	11.91	55.96
36	29	184	10.47	66.43
38	33	217	11.91	78.34
40	31	248	11.19	89.53
42	11	259	3.97	93.50
44	7	266	2.53	96.03
46	8	274	2.89	98.92
48	1	275	0.36	99.28
50	2	277	0.72	100.00
52	0	277	0.00	100.00
54	0	277	0.00	100.00
56	0	277	0.00	100.00
58	0	277	0.00	100.00
60	0	277	0.00	100.00

Figure C15. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 504.8 (Pool 14), nearshore and farshore sites combined, July 1991

```
Shell Length                                   Cumulative  Cumulative
                                         Freq  Freq  Percent  Percent

   6  |                                   0     0    0.00      0.00
   8  |***                                3     3    0.63      0.63
  10  |****                               4     7    0.84      1.46
  12  |***********                       11    18    2.30      3.76
  14  |***************                   15    33    3.13      6.89
  16  |****************                  16    49    3.34     10.23
  18  |***********                       11    60    2.30     12.53
  20  |*****                              5    65    1.04     13.57
  22  |****                               4    69    0.84     14.41
  24  |*                                  1    70    0.21     14.61
  26  |********                           8    78    1.67     16.28
  28  |**********                        10    88    2.09     18.37
  30  |************                      12   100    2.51     20.88
  32  |***********                       11   111    2.30     23.17
  34  |************                      12   123    2.51     25.68
  36  |*****                              5   128    1.04     26.72
  38  |*****                              5   133    1.04     27.77
  40  |****                               4   137    0.84     28.60
  42  |*                                  1   138    0.21     28.81
  44  |****                               4   142    0.84     29.65
  46  |*****                              5   147    1.04     30.69
  48  |***                                3   150    0.63     31.32
  50  |*                                  1   151    0.21     31.52
  52  |********                           8   159    1.67     33.19
  54  |****                               4   163    0.84     34.03
  56  |****                               4   167    0.84     34.86
  58  |****                               4   171    0.84     35.70
  60  |**********                        10   181    2.09     37.79
  62  |**********                        10   191    2.09     39.87
  64  |****************                  16   207    3.34     43.22
  66  |*******************               19   226    3.97     47.18
  68  |***************                   15   241    3.13     50.31
  70  |*************************         25   266    5.22     55.53
  72  |**************************        26   292    5.43     60.96
  74  |**********************            22   314    4.59     65.55
  76  |*******************               19   333    3.97     69.52
  78  |****************************      28   361    5.85     75.37
  80  |******************                18   379    3.76     79.12
  82  |************************          24   403    5.01     84.13
  84  |******************                18   421    3.76     87.89
  86  |************                      12   433    2.51     90.40
  88  |****************                  16   449    3.34     93.74
  90  |**********                        10   459    2.09     95.82
  92  |*****                              5   464    1.04     96.87
  94  |*******                            7   471    1.46     98.33
  96  |****                               4   475    0.84     99.16
  98  |*                                  1   476    0.21     99.37
 100  |                                   0   476    0.00     99.37
 102  |*                                  1   477    0.21     99.58
 104  |*                                  1   478    0.21     99.79
 106  |                                   0   478    0.00     99.79
 108  |                                   0   478    0.00     99.79
 110  |*                                  1   479    0.21    100.00
 112  |                                   0   479    0.00    100.00
 114  |                                   0   479    0.00    100.00
 116  |                                   0   479    0.00    100.00
      -----+----+----+----+----+----
           1    2    3    4    5

              Percentage
```

Figure C16. Shell length (mm) frequency histogram of *Amblema plicata plicata* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
10		0	0	0.00	0.00
12	*********	1	1	4.35	4.35
14	*********	1	2	4.35	8.70
16	*********	1	3	4.35	13.04
18	*********	1	4	4.35	17.39
20		0	4	0.00	17.39
22	*********	1	5	4.35	21.74
24		0	5	0.00	21.74
26	*********	1	6	4.35	26.09
28		0	6	0.00	26.09
30		0	6	0.00	26.09
32	*********	1	7	4.35	30.43
34	*********	1	8	4.35	34.78
36	*****************	2	10	8.70	43.48
38		0	10	0.00	43.48
40	*********	1	11	4.35	47.83
42		0	11	0.00	47.83
44	*****************	2	13	8.70	56.52
46		0	13	0.00	56.52
48		0	13	0.00	56.52
50		0	13	0.00	56.52
52	*********	1	14	4.35	60.87
54	*********	1	15	4.35	65.22
56	**************************	3	18	13.04	78.26
58	*********	1	19	4.35	82.61
60	*********	1	20	4.35	86.96
62		0	20	0.00	86.96
64	*********	1	21	4.35	91.30
66		0	21	0.00	91.30
68		0	21	0.00	91.30
70	*********	1	22	4.35	95.65
72	*********	1	23	4.35	100.00
74		0	23	0.00	100.00
76		0	23	0.00	100.00
78		0	23	0.00	100.00
80		0	23	0.00	100.00
82		0	23	0.00	100.00
84		0	23	0.00	100.00
	2 4 6 8 10 12				
	Percentage				

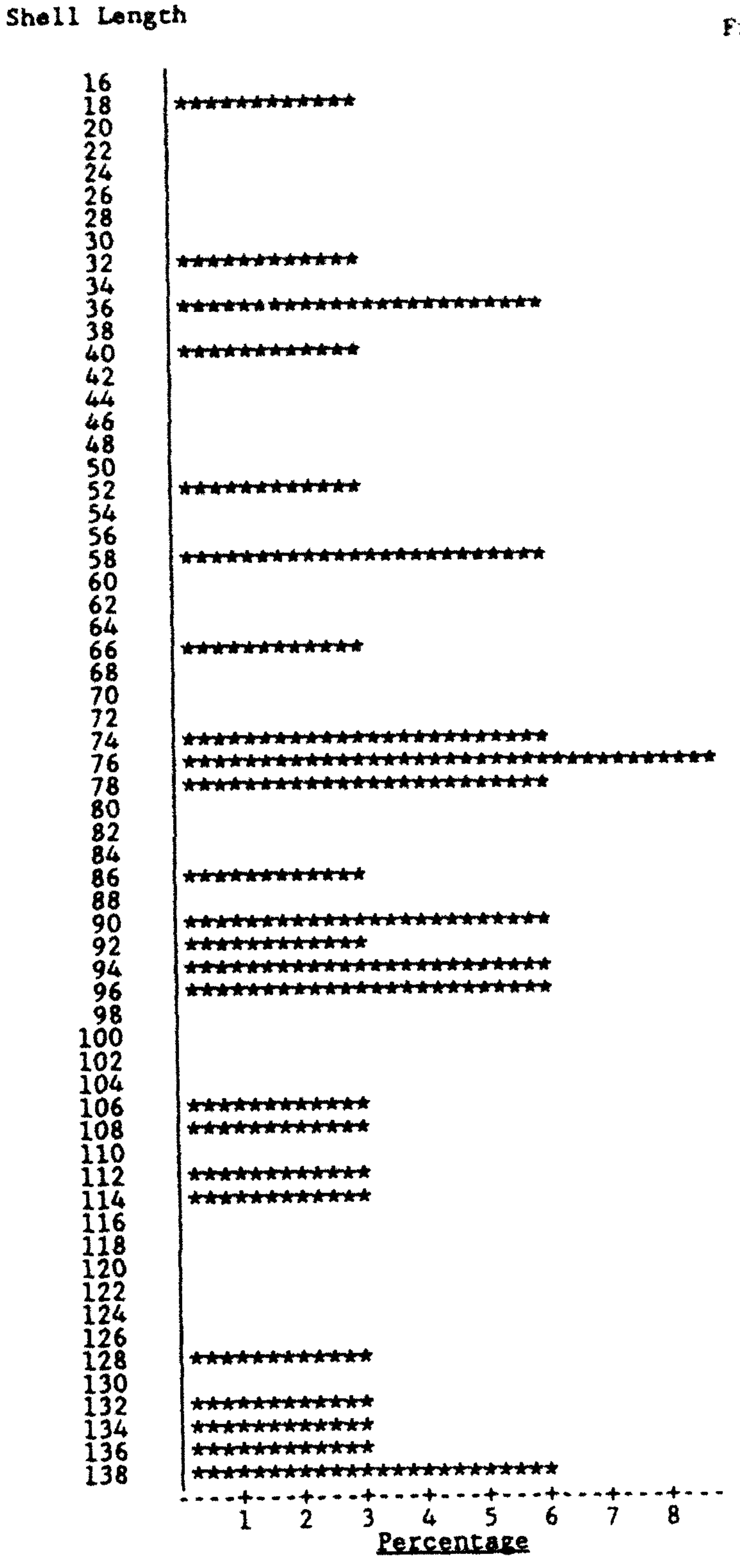
Figure C17. Shell length (mm) frequency histogram of *Fusconaia flava* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20	************	1	1	3.03	3.03
22		0	1	0.00	3.03
24		0	1	0.00	3.03
26		0	1	0.00	3.03
28		0	1	0.00	3.03
30		0	1	0.00	3.03
32		0	1	0.00	3.03
34		0	1	0.00	3.03
36	************	1	2	3.03	6.06
38		0	2	0.00	6.06
40		0	2	0.00	6.06
42		0	2	0.00	6.06
44	************	1	3	3.03	9.09
46	************************	2	5	6.06	15.15
48	************	1	6	3.03	18.18
50	************************	2	8	6.06	24.24
52		0	8	0.00	24.24
54	************	1	9	3.03	27.27
56		0	9	0.00	27.27
58	************	1	10	3.03	30.30
60	************************************	3	13	9.09	39.39
62	************	1	14	3.03	42.42
64	************************************	3	17	9.09	51.52
66	************************	2	19	6.06	57.58
68		0	19	0.00	57.58
70	************	1	20	3.03	60.61
72		0	20	0.00	60.61
74	************************	2	22	6.06	66.67
76	************************	2	24	6.06	72.73
78		0	24	0.00	72.73
80	************	1	25	3.03	75.76
82	************************	2	27	6.06	81.82
84		0	27	0.00	81.82
86	************************	2	29	6.06	87.88
88		0	29	0.00	87.88
90	************	1	30	3.03	90.91
92	************************	2	32	6.06	96.97
94	************	1	33	3.03	100.00
96		0	33	0.00	100.00
98		0	33	0.00	100.00
100		0	33	0.00	100.00

----+---+---+---+---+---+---+---+---+
1 2 3 4 5 6 7 8 9

Percentage

Figure C18. Shell length (mm) frequency histogram of *Leptodea fragilis* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991



Shell Length	Freq	Cumulative Freq	Percent	Cumulative Percent
16	0	0	0.00	0.00
18	1	1	2.94	2.94
20	0	1	0.00	2.94
22	0	1	0.00	2.94
24	0	1	0.00	2.94
26	0	1	0.00	2.94
28	0	1	0.00	2.94
30	0	1	0.00	2.94
32	1	2	2.94	5.88
34	0	2	0.00	5.88
36	2	4	5.88	11.76
38	0	4	0.00	11.76
40	1	5	2.94	14.71
42	0	5	0.00	14.71
44	0	5	0.00	14.71
46	0	5	0.00	14.71
48	0	5	0.00	14.71
50	0	5	0.00	14.71
52	1	6	2.94	17.65
54	0	6	0.00	17.65
56	0	6	0.00	17.65
58	2	8	5.88	23.53
60	0	8	0.00	23.53
62	0	8	0.00	23.53
64	0	8	0.00	23.53
66	1	9	2.94	26.47
68	0	9	0.00	26.47
70	0	9	0.00	26.47
72	0	9	0.00	26.47
74	2	11	5.88	32.35
76	3	14	8.82	41.18
78	2	16	5.88	47.06
80	0	16	0.00	47.06
82	0	16	0.00	47.06
84	0	16	0.00	47.06
86	1	17	2.94	50.00
88	0	17	0.00	50.00
90	2	19	5.88	55.88
92	1	20	2.94	58.82
94	2	22	5.88	64.71
96	2	24	5.88	70.59
98	0	24	0.00	70.59
100	0	24	0.00	70.59
102	0	24	0.00	70.59
104	0	24	0.00	70.59
106	1	25	2.94	73.53
108	1	26	2.94	76.47
110	0	26	0.00	76.47
112	1	27	2.94	79.41
114	1	28	2.94	82.35
116	0	28	0.00	82.35
118	0	28	0.00	82.35
120	0	28	0.00	82.35
122	0	28	0.00	82.35
124	0	28	0.00	82.35
126	0	28	0.00	82.35
128	1	29	2.94	85.29
130	0	29	0.00	85.29
132	1	30	2.94	88.24
134	1	31	2.94	91.18
136	1	32	2.94	94.12
138	2	34	5.88	100.00

Figure C19. Shell length (mm) frequency histogram of *Megalonaias nervosa* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18		0	0	0.00	0.00
20	*******	2	2	7.14	7.14
22	*******	2	4	7.14	14.29
24	***********	3	7	10.71	25.00
26	*******	2	9	7.14	32.14
28		0	9	0.00	32.14
30		0	9	0.00	32.14
32	*******	2	11	7.14	39.29
34	*******	2	13	7.14	46.43
36	*************************	7	20	25.00	71.43
38		0	20	0.00	71.43
40		0	20	0.00	71.43
42	****	1	21	3.57	75.00
44		0	21	0.00	75.00
46	***********	3	24	10.71	85.71
48	*******	2	26	7.14	92.86
50	*******	2	28	7.14	100.00
52		0	28	0.00	100.00
54		0	28	0.00	100.00
56		0	28	0.00	100.00
58		0	28	0.00	100.00
60		0	28	0.00	100.00
150		0	28	0.00	100.00
	5 10 15 20 25				
	Percentage				

Figure C20. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
46		0	0	0.00	0.00
48		0	0	0.00	0.00
50		0	0	0.00	0.00
52	********	1	1	4.00	4.00
54		0	1	0.00	4.00
56		0	1	0.00	4.00
58		0	1	0.00	4.00
60		0	1	0.00	4.00
62	************************	3	4	12.00	16.00
64	****************	2	6	8.00	24.00
66	********	1	7	4.00	28.00
68	****************	2	9	8.00	36.00
70	************************	3	12	12.00	48.00
72	************************	3	15	12.00	60.00
74		0	15	0.00	60.00
76	****************	2	17	8.00	68.00
78	********	1	18	4.00	72.00
80	********	1	19	4.00	76.00
82		0	19	0.00	76.00
84	********	1	20	4.00	80.00
86		0	20	0.00	80.00
88		0	20	0.00	80.00
90		0	20	0.00	80.00
92		0	20	0.00	80.00
94	********	1	21	4.00	84.00
96	********	1	22	4.00	88.00
98		0	22	0.00	88.00
100	********	1	23	4.00	92.00
102		0	23	0.00	92.00
104		0	23	0.00	92.00
106		0	23	0.00	92.00
108		0	23	0.00	92.00
110		0	23	0.00	92.00
112		0	23	0.00	92.00
114		0	23	0.00	92.00
116		0	23	0.00	92.00
118	****************	2	25	8.00	100.00
120		0	25	0.00	100.00
122		0	25	0.00	100.00
124		0	25	0.00	100.00
126		0	25	0.00	100.00
128		0	25	0.00	100.00
130		0	25	0.00	100.00

2 4 6 8 10 12

Percentage

Figure C21. Shell length (mm) frequency histogram of *Potamilus alatus* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12	**	1	1	0.81	0.81
14	*****	3	4	2.44	3.25
16	**	1	5	0.81	4.07
18	********	5	10	4.07	8.13
20	****************	10	20	8.13	16.26
22	*****************************	18	38	14.63	30.89
24	**************************	16	54	13.01	43.90
26	********	5	59	4.07	47.97
28	********	5	64	4.07	52.03
30	**********	6	70	4.88	56.91
32	**********	6	76	4.88	61.79
34	*************	8	84	6.50	68.29
36	*******	4	88	3.25	71.54
38	********************	12	100	9.76	81.30
40	********	5	105	4.07	85.37
42	**********	6	111	4.88	90.24
44	**	1	112	0.81	91.06
46	********	5	117	4.07	95.12
48	**	1	118	0.81	95.93
50	**	1	119	0.81	96.75
52	***	2	121	1.63	98.37
54	**	1	122	0.81	99.19
56		0	122	0.00	99.19
58	**	1	123	0.81	100.00
60		0	123	0.00	100.00
62		0	123	0.00	100.00
64		0	123	0.00	100.00
66		0	123	0.00	100.00
68		0	123	0.00	100.00
70		0	123	0.00	100.00

----+---+---+---+---+---+---+-
2 4 6 8 10 12 14

Percentage

Figure C22. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 635.2 (Pool 10), nearshore and farshore sites combined, July 1991

APPENDIX D: SUMMARY STATISTICS FOR WATER VELOCITY DATA COLLECTED IN THE UPPER MISSISSIPPI RIVER (UMR), 1991

Table D1

Summary Statistics for an Increment of Water Velocity Data (200 Seconds) During and Immediately Before or After Passage of a Commercial Navigation Vessel

	Y	X	Combined Velocity	Flow Direction
			8 July 1991 - File A911894	
Sensor 942 - Before Test 4				
Mean	1.51	1.02	1.83	127.06
SD	C.36	0.24	0.40	5.36
Min	0.70	0.37	1.02	110.80
Max	2.39	1.63	2.84	144.10
Range	1.68	1.26	1.82	33.30
N	200			
Seconds: 73-272				
Sensor 946 - During Test 4				
Mean	2.10	-0.02	2.10	97.24
SD	0.34	0.11	0.34	2.97
Min	1.10	-0.22	1.10	90.40
Max	2.84	0.39	2.84	108.90
Range	1.75	0.61	1.75	18.50
N	200			
Seconds: 73 - 272				
Sensor 942 - During Test 4				
Mean	1.67	1.09	2.01	126.56
SD	0.27	0.28	0.32	5.01
Min	0.60	-0.33	0.63	112.60
Max	2.18	1.66	2.53	146.50
Range	1.58	1.99	1.90	33.90
N	200			
Seconds: 300-499				
Sensor 946 - After Test 4				
Mean	2.08	-0.06	2.09	96.20
SD	0.35	0.20	0.34	4.24
Min	1.19	-1.21	1.20	76.00
Max	3.00	0.33	3.00	106.30
Range	1.81	1.54	1.81	30.30
N	200			
Seconds: 300-499				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
			8 July 1991 - File B911894	
Sensor 939 - Before Test 4				
Mean	2.18	0.08	2.19	109.24
SD	0.40	0.09	0.40	2.41
Min	1.36	-0.16	1.36	103.20
Max	3.28	0.32	3.28	114.70
Range	1.92	0.48	1.92	11.50
N	200			
Seconds: 73-272				
Sensor 940 - Before Test 4				
Mean	2.34	-0.21	2.36	125.[illegible]
SD	0.44	0.20	0.45	4.[illegible]
Min	1.25	-0.78	1.26	110.70
Max	3.36	0.29	3.39	139.50
Range	2.11	1.06	2.13	28.80
N	200			
Seconds: 73-272				
Sensor 939 - After Test 4				
Mean	2.38	0.09	2.39	111.19
SD	0.38	0.09	0.37	11.35
Min	1.59	-0.19	1.59	101.90
Max	3.20	0.28	3.20	184.00
Range	1.61	0.48	1.61	82.10
N	200			
Seconds: 300-499				
Sensor 940 - After Test 4				
Mean	2.54	-0.27	2.56	125.31
SD	0.40	0.23	0.40	7.09
Min	1.68	-0.81	1.70	113.80
Max	3.47	0.39	3.52	162.10
Range	1.79	1.20	1.82	48.30
N	200			
Seconds: 300-499				

(Continued)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
		8 July 1991 - File A911903		
Sensor 942 - Before Test 7				
Mean	0.81	0.48	0.95	130.86
SD	0.09	0.13	0.12	6.43
Min	0.57	0.09	0.63	107.80
Max	1.04	0.93	1.32	147.60
Range	0.47	0 84	0.70	39.80
N	200			
Seconds: 1040-1239				
Sensor 946 - Before Test 7				
Mean	2.33	-0.41	2.53	258.57
SD	0.18	0.97	0.42	19.67
Min	1.90	-3.34	2.03	213.60
Max	2.91	2.38	4.33	317.40
Range	1.01	5.71	2.31	103.80
N	200			
Seconds: 1040-1239				
Sensor 942 - During Test 7				
Mean	0.62	0.34	0.71	128.71
SD	0.14	0.12	0.16	7.92
Min	0.33	-0.01	0.39	107.80
Max	0.94	0.69	1.04	146.60
Range	0.61	0.70	0.65	38.80
N	200			
Seconds: 1240-1439				
Sensor 946 - During Test 7				
Mean	1.76	0.30	2.08	276.24
SD	0.29	1.14	0.46	29.04
Min	0.99	-2.36	1.33	216.30
Max	2.34	3.27	3.51	334.70
Range	1.35	5.63	2.19	118.40
N	200			
Seconds: 1240-1439				

(Continued)

(Sheet 3 of 8)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
			8 July 1991 - File B911903	
Sensor 939 - Before Test 7				
Mean	1.55	-0.23	1.59	111.10
SD	0.31	0.27	0.32	6.85
Min	0.96	-1.02	0.96	87.70
Max	2.33	0.41	2.46	137.50
Range	1.37	1.43	1.49	50.30
N	200			
Seconds: 1040-1239				
Sensor 940 - Before Test 7				
Mean	2.45	-0.84	2.60	117.96
SD	0.36	0.26	0.38	5.98
Min	1.53	-1.[illegible]	1.73	98.20
Max	3.30	-0.06	3.44	135.70
Range	1.76	1.5[illegible]	1.71	37.50
N	200			
Seconds: 1040-1239				
Sensor 939 - During Test 7				
Mean	1.30	-0.07	1.31	116.15
SD	0.31	0.18	0.31	8.03
Min	0.72	-0.56	0.72	94.70
Max	2.46	0.34	2.46	142.60
Range	1.75	0.90	1.75	47.90
N	200			
Seconds: 1240-1439				
Sensor 940 - During Test 7				
Mean	2.17	-0.68	2.29	119.52
SD	0.38	0.26	0.39	6.37
Min	1.43	-1.36	1.54	96.80
Max	3.09	0.00	3.23	136.90
Range	1.66	1.36	1.69	40.10
N	200			
Seconds: 1240-1439				

(Continued)

(Sheet 4 of 8)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
		4 July 1991 - File A911904		
Sensor 942 - Before Test 8				
Mean	0.67	0.41	0.79	131.98
SD	0.10	0.12	0.13	7.07
Min	0.38	0.14	1.57	-1.57
Max	0.94	0.74	1.17	151.20
Range	0.55	0.59	2.74	152.77
N	200			
Seconds: 50-249				
Sensor 946 - Before Test 8				
Mean	1.97	0.00	2.08	267.52
SD	0.10	0.17	0.25	18.76
Min	1.45	-1.53	1.68	231.10
Max	2.40	1.42	2.77	310.30
Range	0.95	2.95	1.09	79.20
N	200			
Seconds: 50-249				
Sensor 942 - During Test 8				
Mean	0.74	0.45	0.87	131.55
SD	0.09	0.09	0.11	4.64
Min	0.53	0.23	-1.73	-1.73
Max	0.96	0.72	1.14	144.60
Range	0.44	0.49	2.87	146.33
N	200			
Seconds: 274-473				
Sensor 946 - During Test 8				
Mean	2.02	-0.08	2.20	265.32
SD	0.09	0.10	0.30	22.47
Min	1.57	-1.73	1.64	229.80
Max	2.59	2.26	2.98	319.50
Range	1.02	3.99	1.34	89.70
N	200			
Seconds: 274-473				

(Continued)

(Sheet 5 of 8)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
		8 July 1991 - File B911904		
Sensor 939 - Before Test 8				
Mean	1.45	-0.08	1.46	115.82
SD	0.30	0.20	0.30	7.74
Min	0.84	-0.67	0.84	-0.67
Max	2.23	0.44	2.23	0.44
Range	1.39	1.11	1.39	1.11
N	200			
Seconds: 50-249				
Sensor 940 - Before Test 8				
Mean	2.31	-0.78	2.45	119.15
SD	0.35	0.27	0.35	6.36
Min	1.38	-1.48	1.53	94.40
Max	3.06	0.07	3.17	139.70
Range	1.69	1.55	1.64	45.30
N	200			
Seconds: 50-249				
Sensor 939 - During Test 8				
Mean	1.55	-0.21	1.58	111.36
SD	0.32	0.21	0.32	7.60
Min	0.92	-0.80	0.92	-0.80
Max	2.59	0.47	2.59	0.47
Range	1.67	1.27	1.67	1.27
N	200			
Seconds: 274-473				
Sensor 940 - During Test 8				
Mean	2.23	-0.80	2.39	117.79
SD	0.41	0.27	0.39	7.14
Min	1.35	-1.51	1.51	98.60
Max	3.14	0.04	3.25	138.70
Range	1.79	1.55	1.74	40.10
N	200			
Seconds: 274-473				

(Continued)

(Sheet 6 of 8)

Table D1 (Continued)

	Y	X	Combined Velocity	Flow Direction
			10 July 1991 - File A911941	
Sensor 942 - During Test 15				
Mean	0.71	0.36	0.80	169.37
SD	0.12	0.07	0.13	3.72
Min	0.40	0.21	0.53	161.20
Max	0.91	0.52	1.00	182.40
Range	0.51	0.30	0.47	21.20
N	200			
Seconds: 50-249				
Sensor 942 - After Test 15				
Mean	0.43	0.35	0.56	164.34
SD	0.03	0.04	0.03	4.08
Min	0.31	0.27	0.49	155.10
Max	0.50	0.46	0.62	186.40
Range	0.19	0.19	0.13	31.30
N	200			
Seconds: 300-499				
			13 July 1991 - File A911943	
Sensor 939 - During Test 17				
Mean	0.39	0.28	0.48	158.91
SD	0.05	0.03	0.05	4.78
Min	0.27	0.21	0.36	148.20
Max	0.50	0.37	0.59	169.00
Range	0.23	0.16	0.24	20.80
N	200			
Seconds: 50-249				
Sensor 939 - After Test 17				
Mean	0.49	0.32	0.58	157.76
SD	0.04	0.03	0.04	2.11
Min	0.39	0.24	0.48	152.00
Max	0.59	0.37	0.68	164.00
Range	0.20	0.13	0.20	12.00
N	200			
Seconds: 300-499				

(Continued)

Table D1 (Concluded)

	Y	X	Combined Velocity	Flow Direction
			16 July 1991 - File B911963	
Sensor 939 - During Test 26				
Mean	1.67	0.06	1.77	297.30
SD	0.41	0.59	0.41	19.81
Min	0.38	-1.26	0.41	235.50
Max	2.65	1.75	2.78	353.60
Range	2.27	3.01	2.37	118.10
N	200			
Seconds: 120-319				
Sensor 940 - During Test 26				
Mean	0.75	1.66	1.83	171.00
SD	0.11	0.13	0.17	2.19
Min	0.49	1.39	1.51	166.50
Max	1.01	2.00	2.21	178.10
Range	0.52	0.62	0.71	11.60
N	200			
Seconds: 120-319				
Sensor 939 - After Test 27				
Mean	1.68	0.03	1.73	297.68
SD	0.53	0.36	0.51	23.17
Min	-0.13	-0.91	0.19	233.20
Max	2.93	1.06	3.04	546.90
Range	3.06	1.97	2.85	313.70
N	200			
Seconds: 400-599				
Sensor 940 - After Test 27				
Mean	0.75	1.69	1.85	171.25
SD	0.12	0.16	0.18	2.41
Min	0.53	1.34	1.46	166.10
Max	0.89	1.91	2.24	176.60
Range	0.36	0.58	0.78	10.50
N	200			
Seconds: 400-599				

(Sheet 8 of 8)

APPENDIX E: INDIVIDUAL PLOTS FOR WATER VELOCITY, COMBINED (OR NET) VELOCITY, AND DIRECTION OF FLOW FOR SELECTED VESSEL PASSAGE EVENTS IN THE UPPER MISSISSIPPI RIVER (UMR), 1991. SEE TABLE 9 AND MAIN TEXT FOR MORE DETAILS

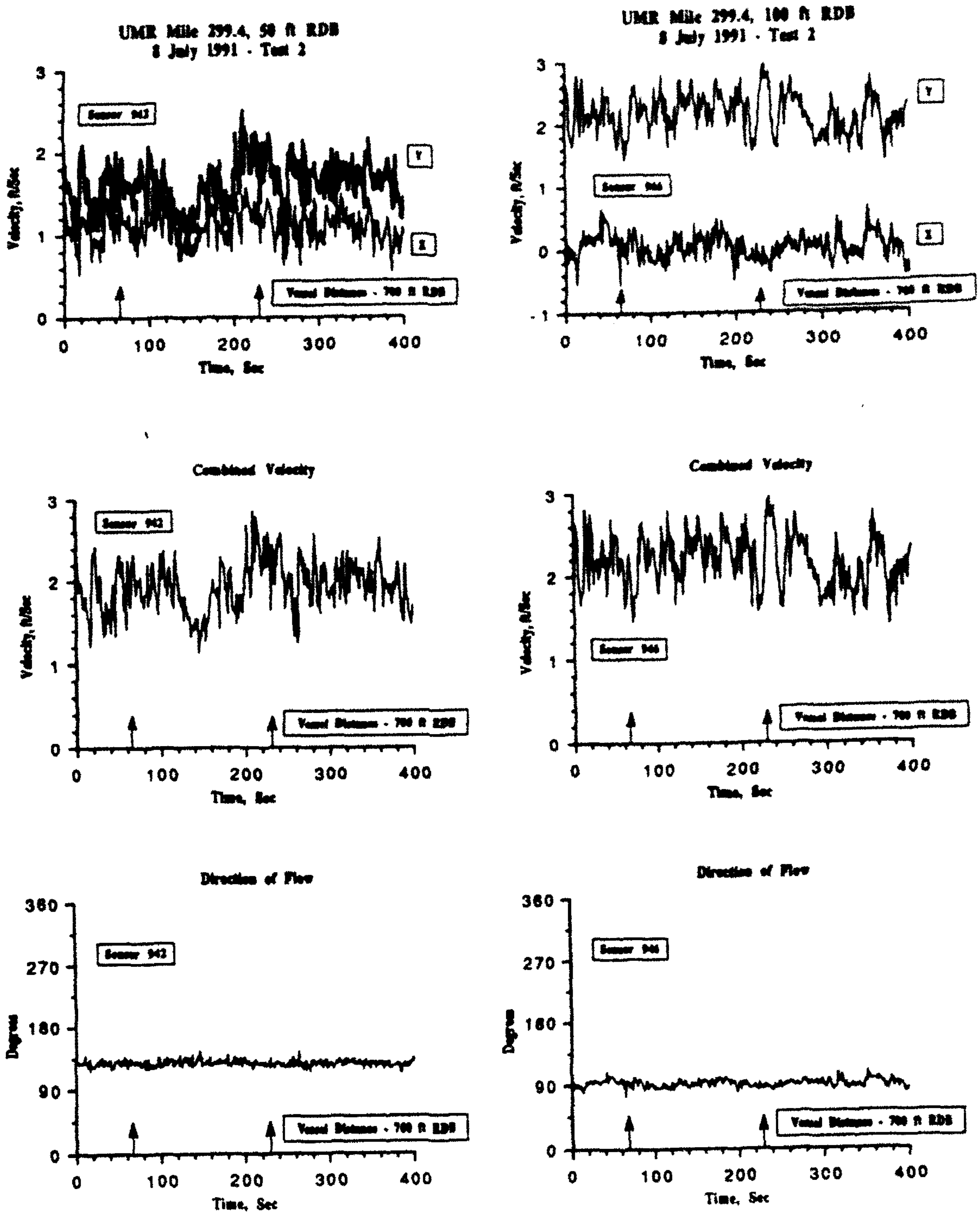


Figure E1. Test 2, river mile (RM) 299.4, 50 and 100 ft right descending bank (RDB), 8 July 1991

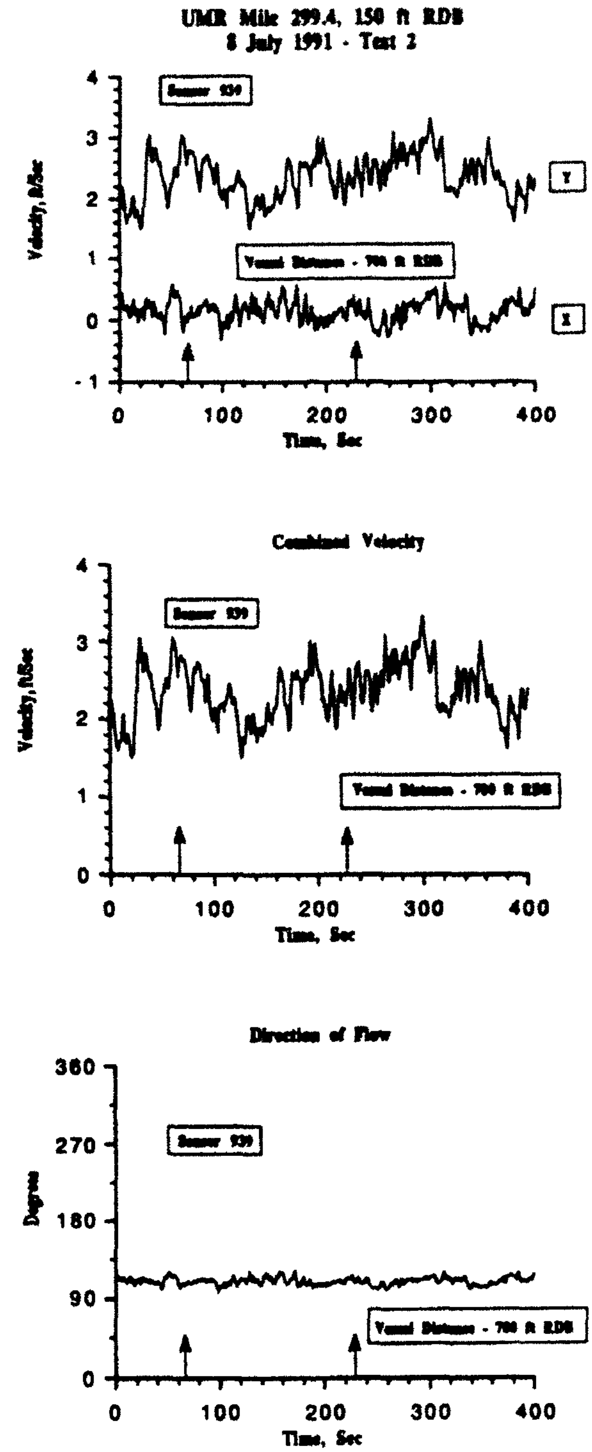


Figure E2. Test 2, RM 299.4, 150 ft RDB, 8 July 1991

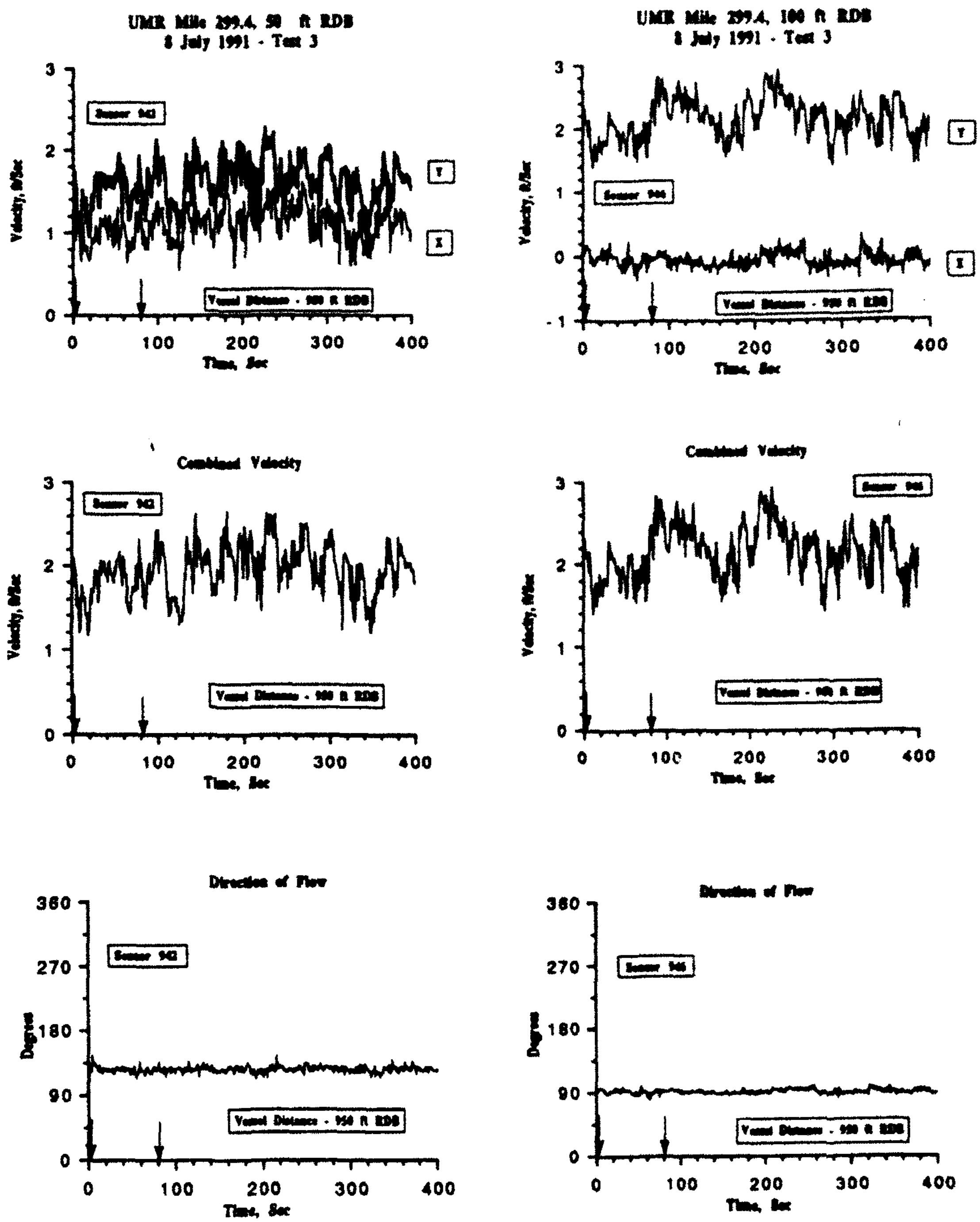


Figure E3. Test 3, RM 299.4, 50 and 100 ft RDB, 8 July 1991

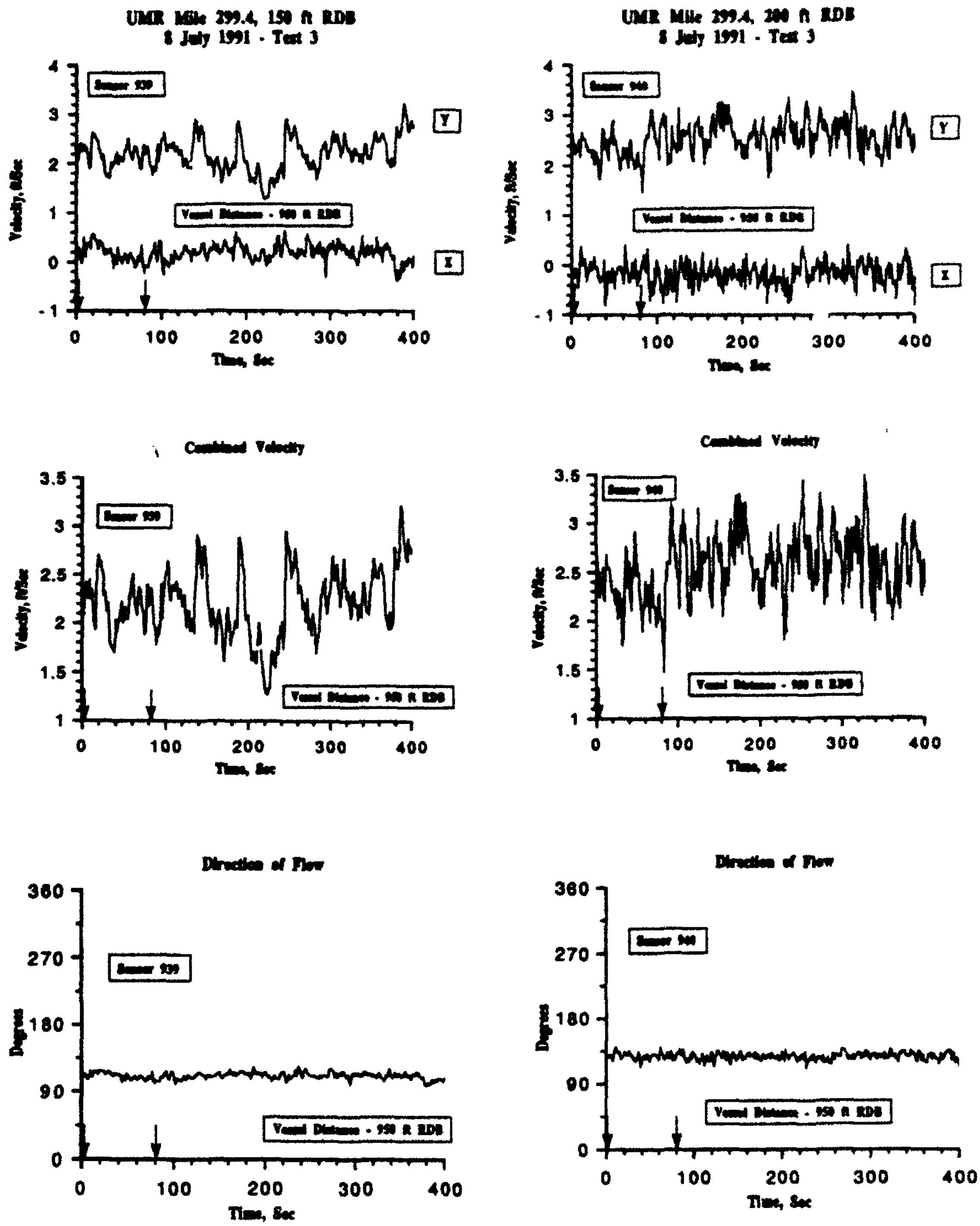


Figure E4. Test 3, RM 299.4, 150 and 200 ft RDB, 8 July 1991

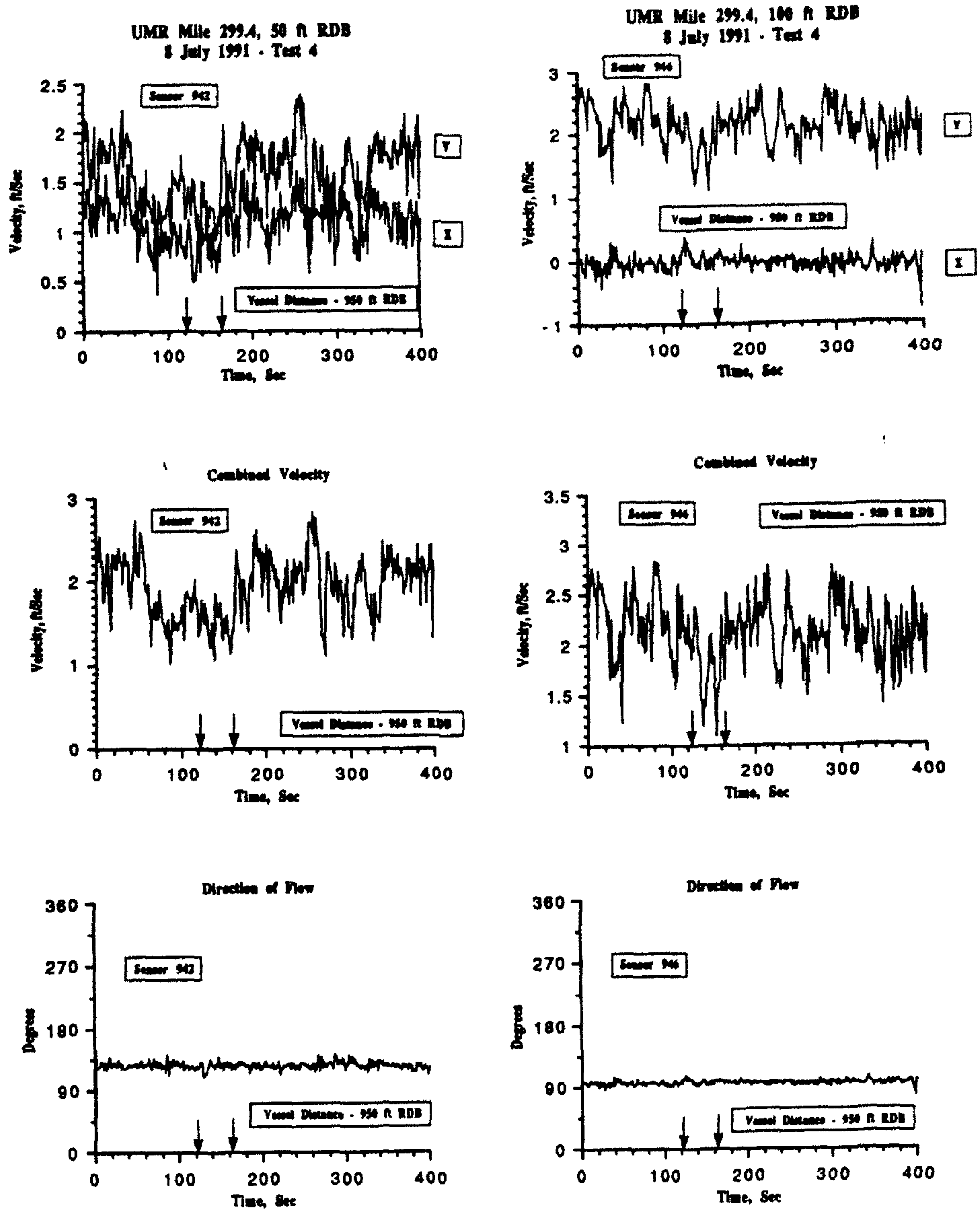


Figure E5. Test 4, RM 299.4, 50 and 100 ft RDB, 8 July 1991

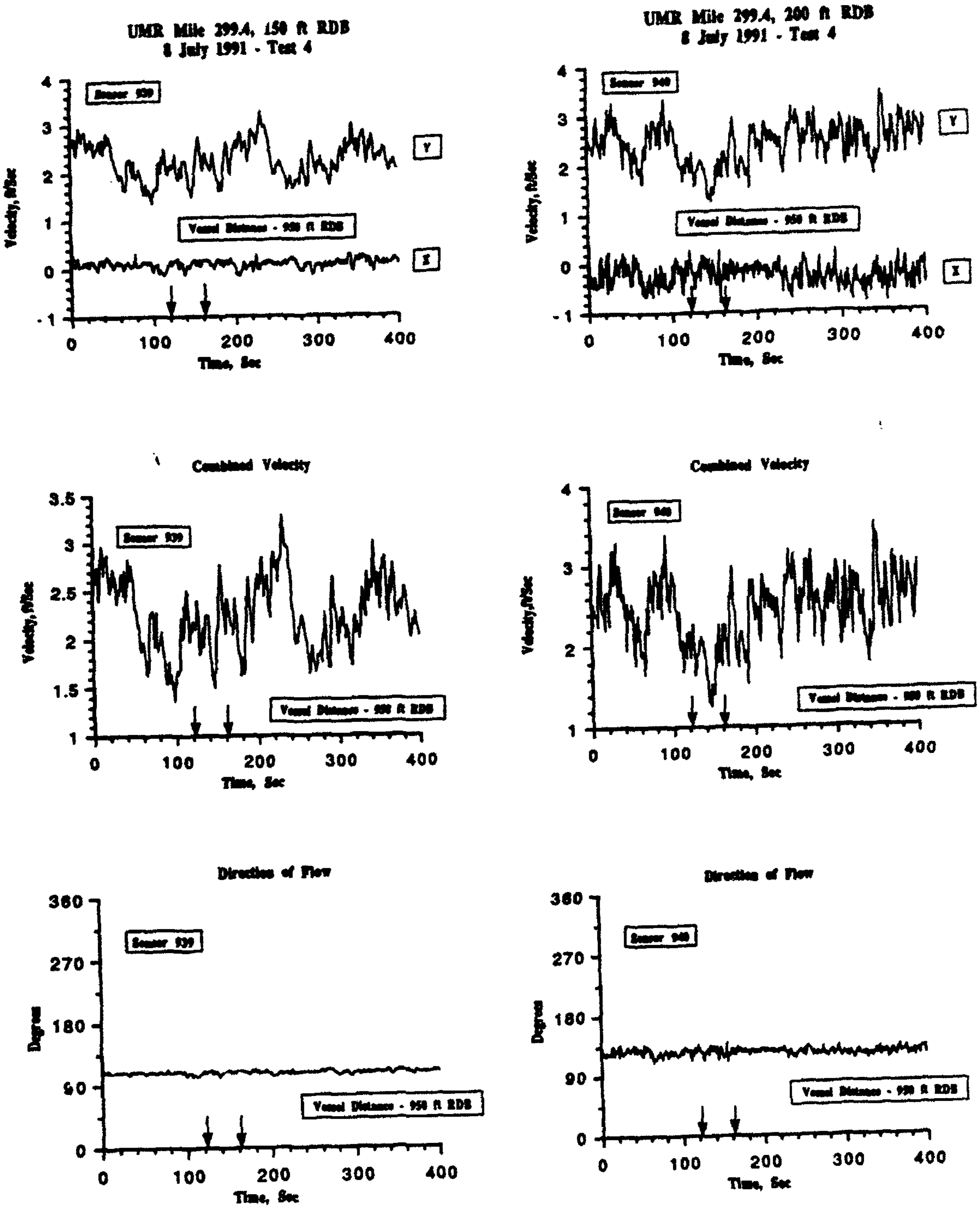


Figure E6. Test 4, RM 299.4, 150 and 200 ft RDB, 8 July 1991

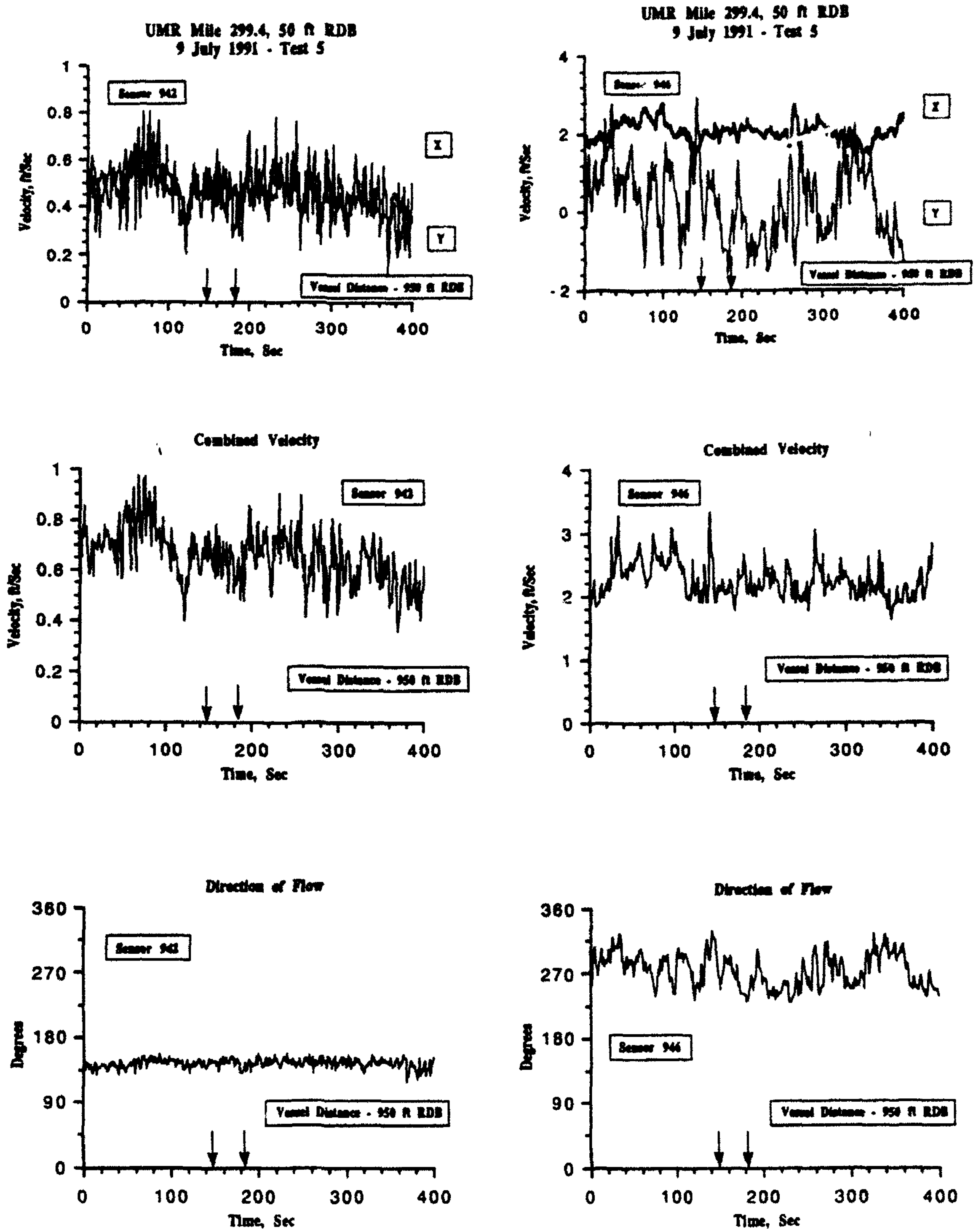


Figure E7. Test 5, RM 299.4, 50 ft RDB, 9 July 1991

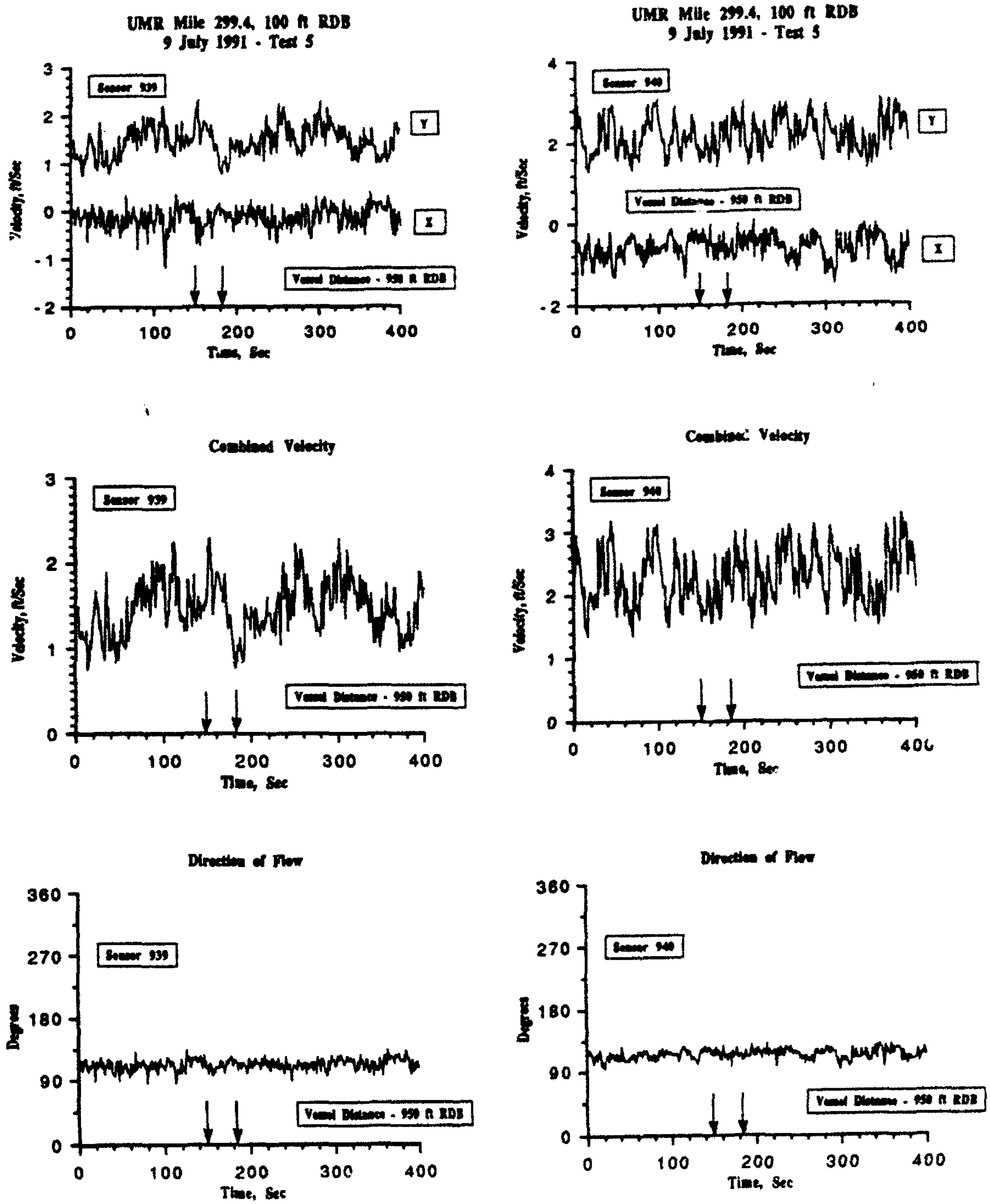


Figure E8. Test 5, RM 299.4, 100 ft RDB, 9 July 1991

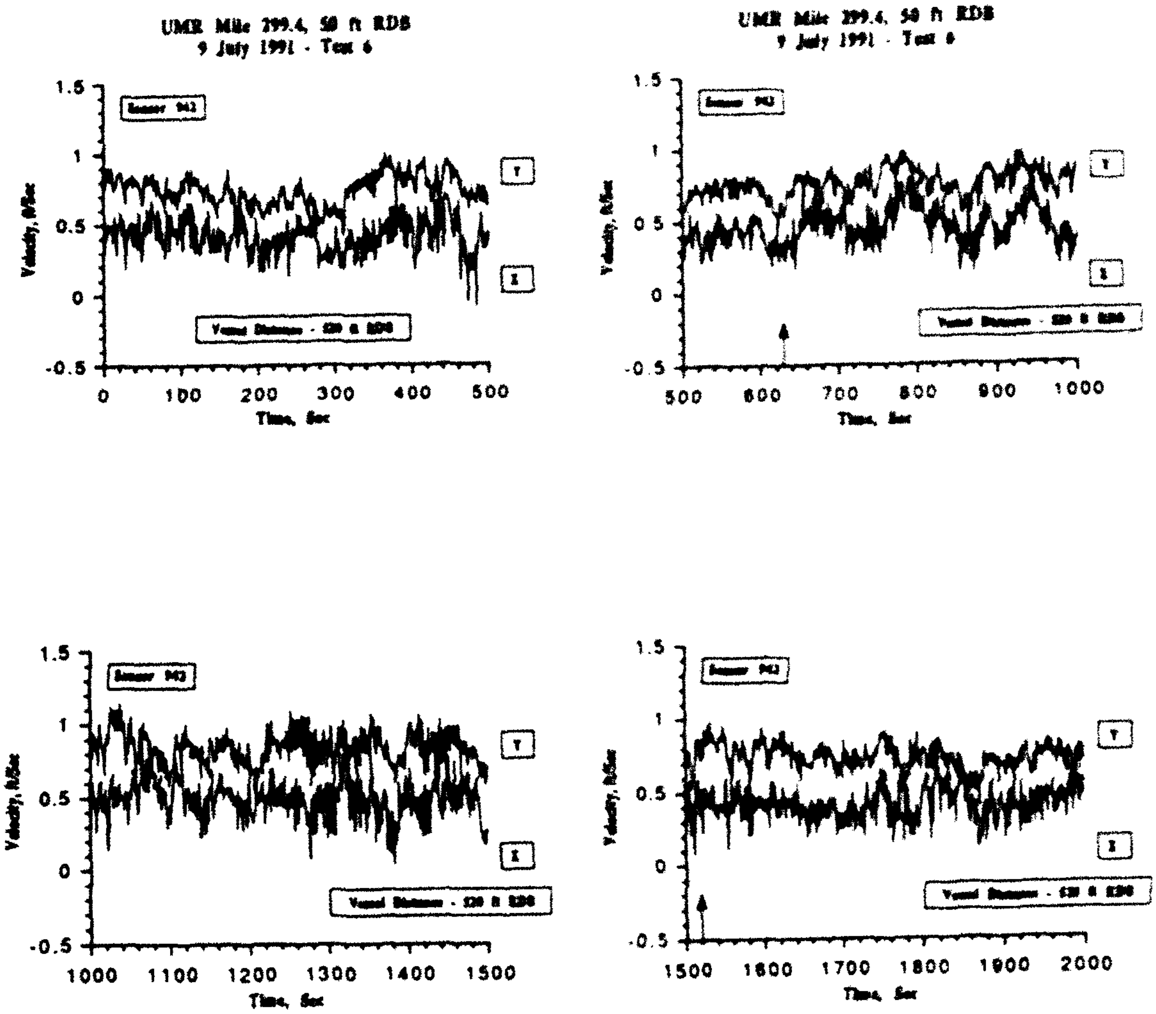


Figure E9. Test 6, RM 299.4, 50 ft RDB, 9 July 1991

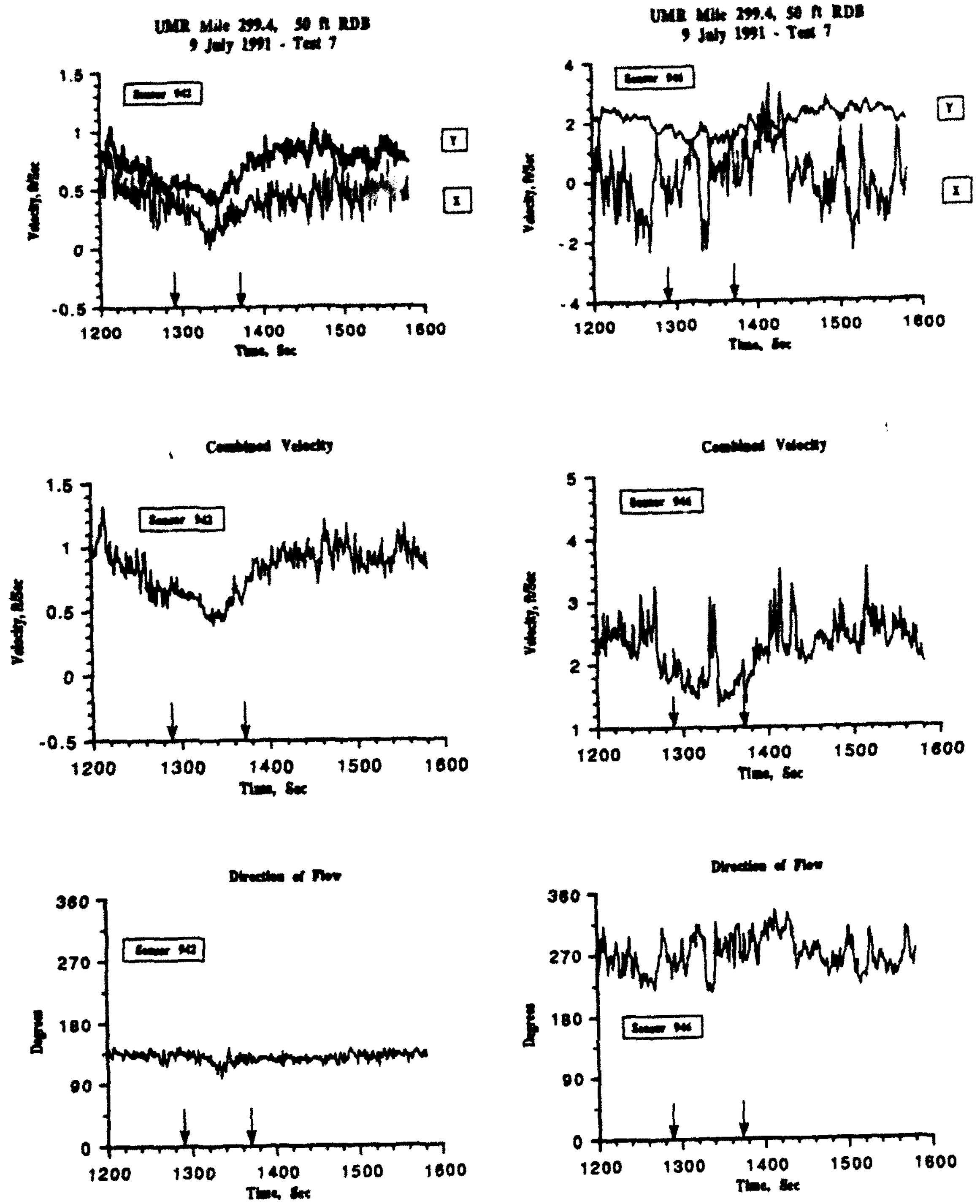


Figure E10. Test 7, RM 299.4, 50 ft RDB, 9 July 1991

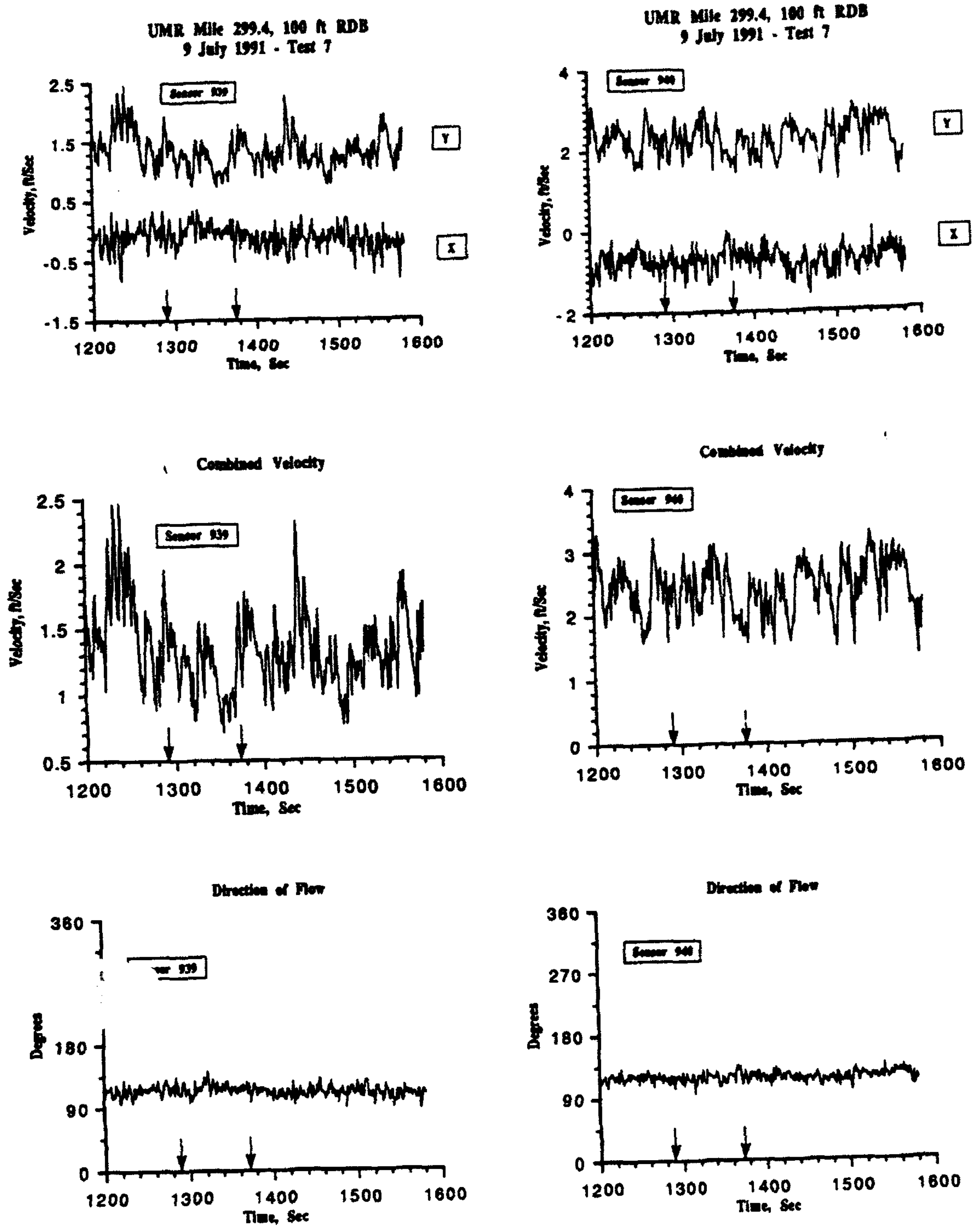


Figure E11. Test 7, RM 299.4, 100 ft RDB, 9 July 1991

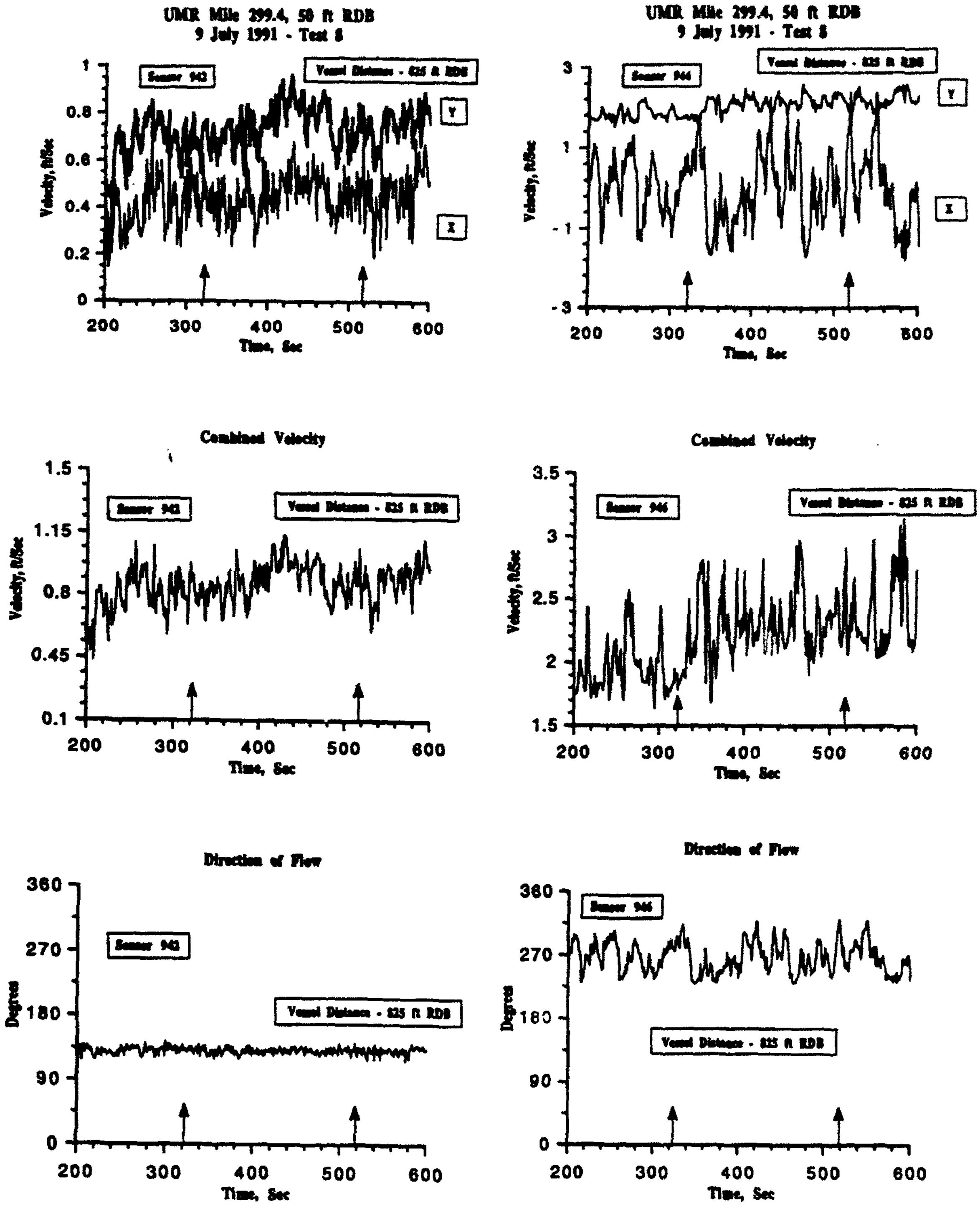


Figure E12. Test 8, RM 299.4, 50 ft RDB, 9 July 1991

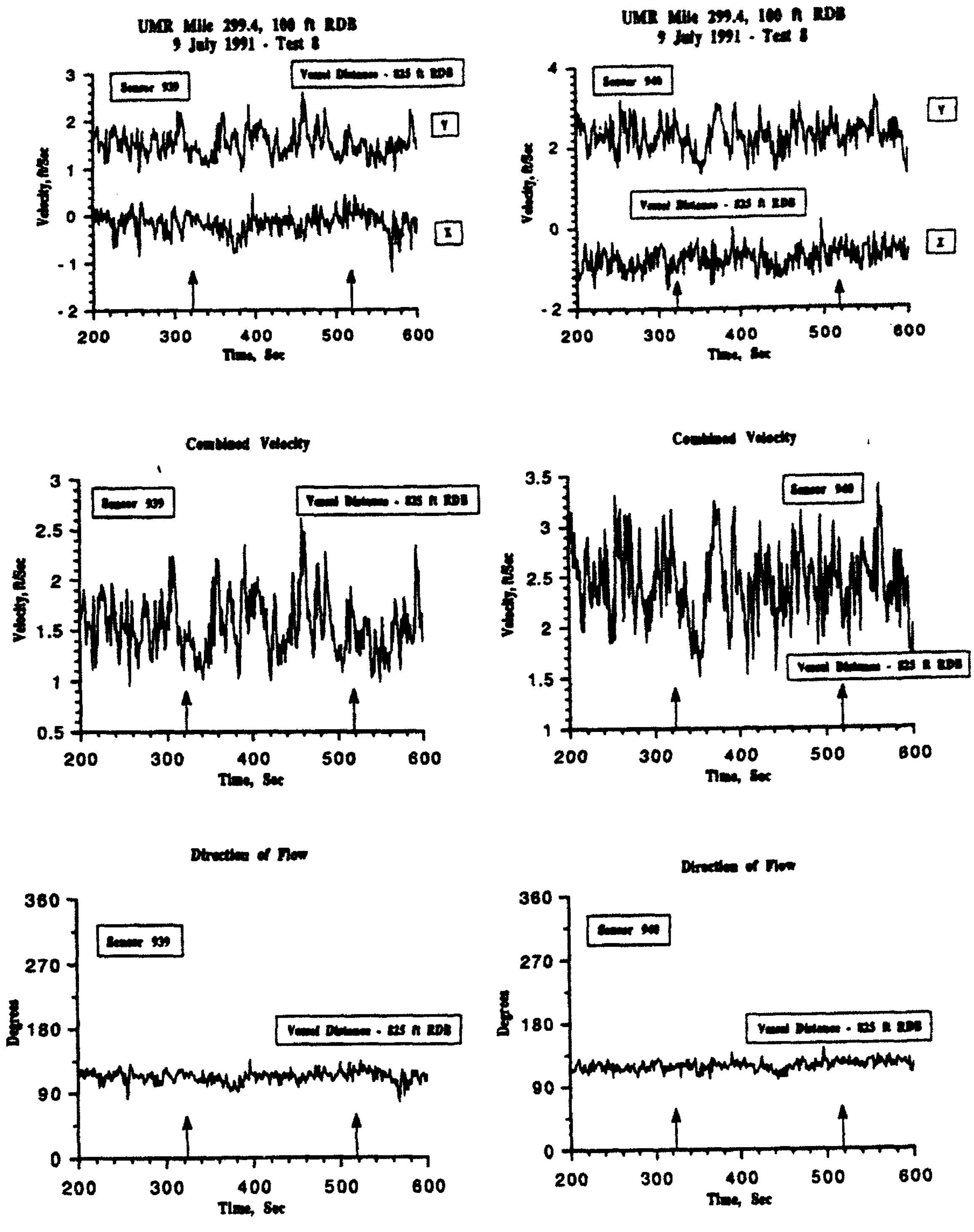


Figure E13. Test 8, RM 299.4, 100 ft RDB, 9 July 1991

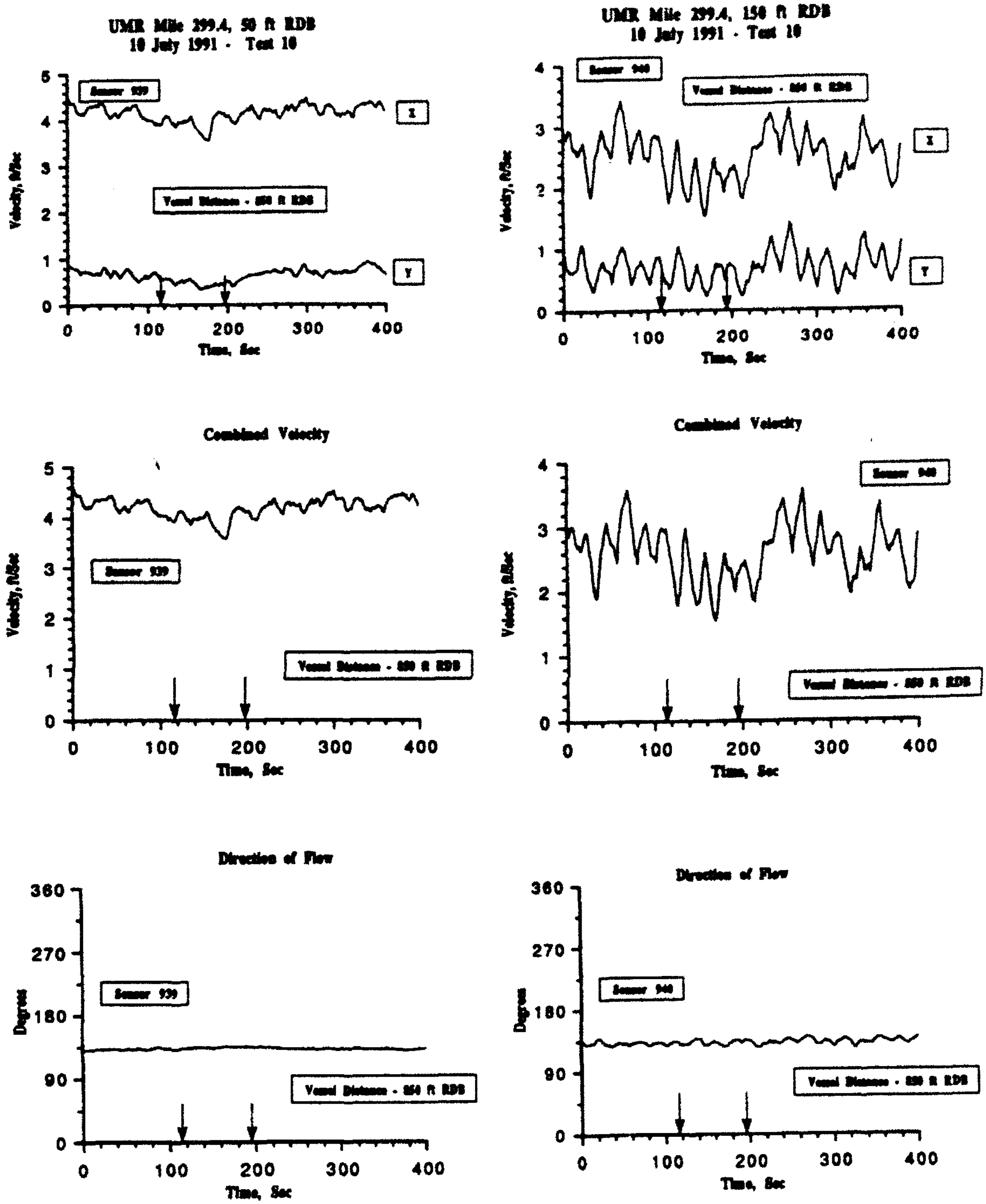


Figure E14. Test 10, RM 299.4, 50 and 150 ft RDB, 10 July 1991

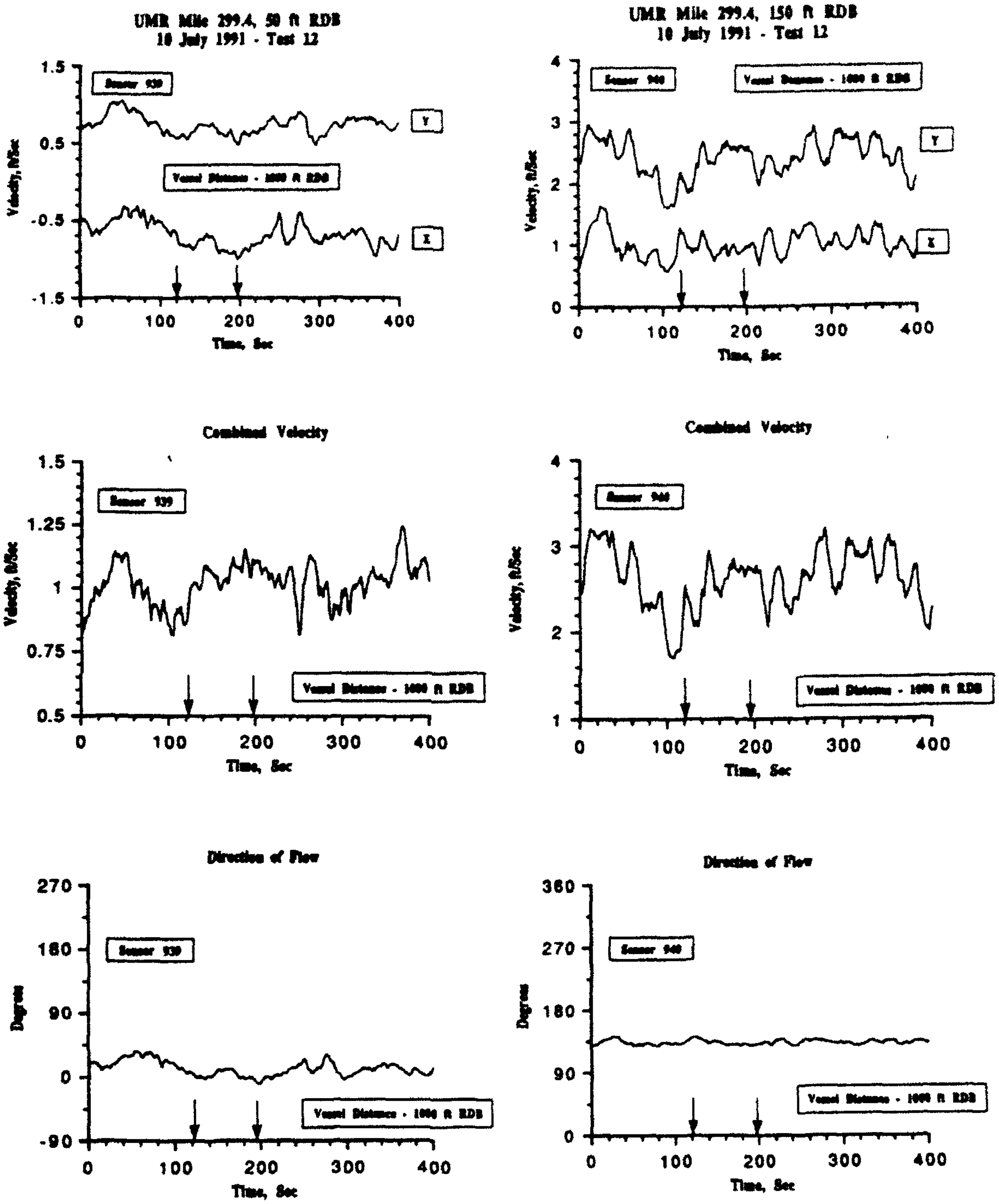


Figure E15. Test 12, RM 299.4, 50 and 150 ft RDB, 10 July 1991

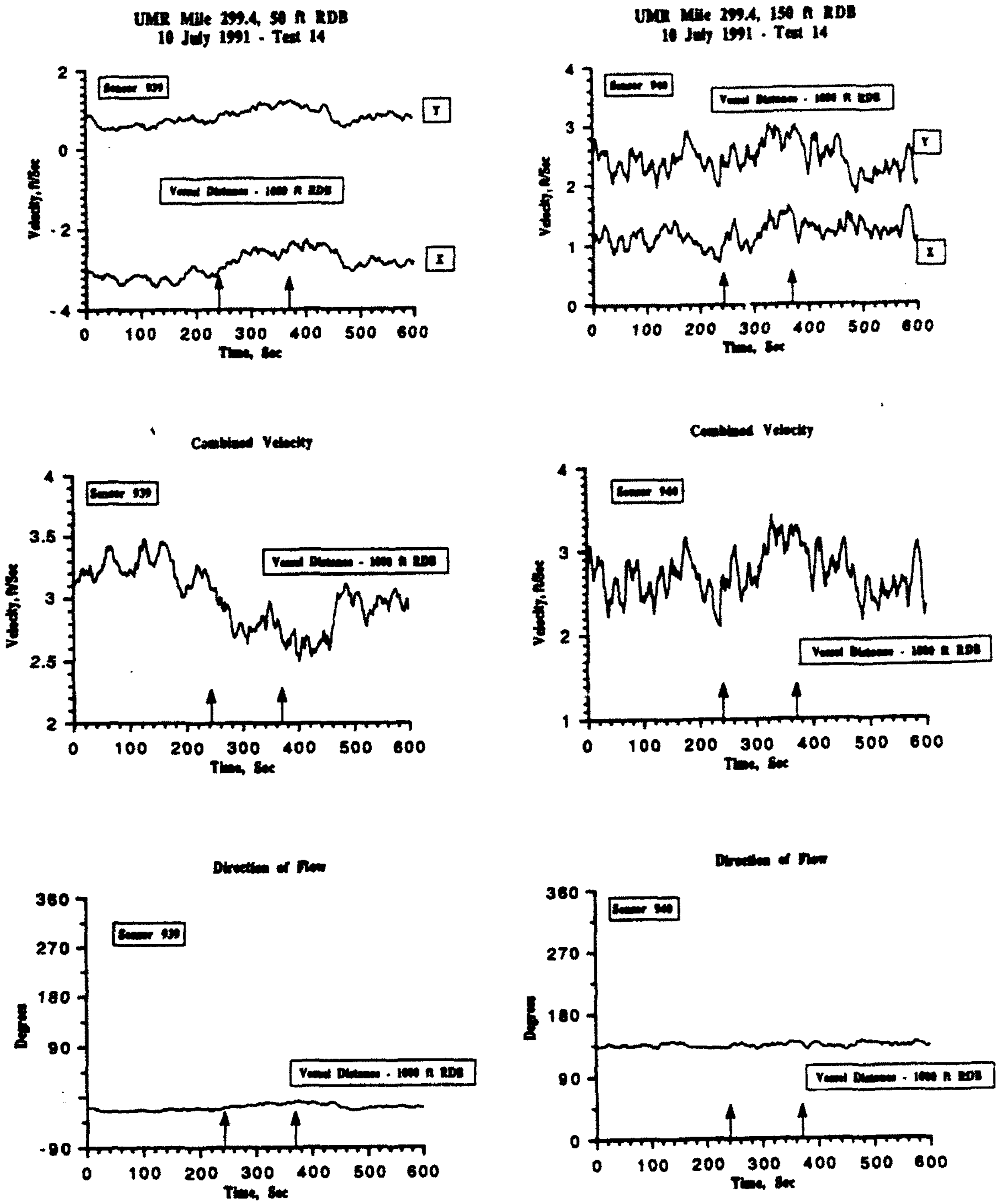


Figure E16. Test 14, RM 299.4, 50 and 150 ft RDB, 10 July 1991

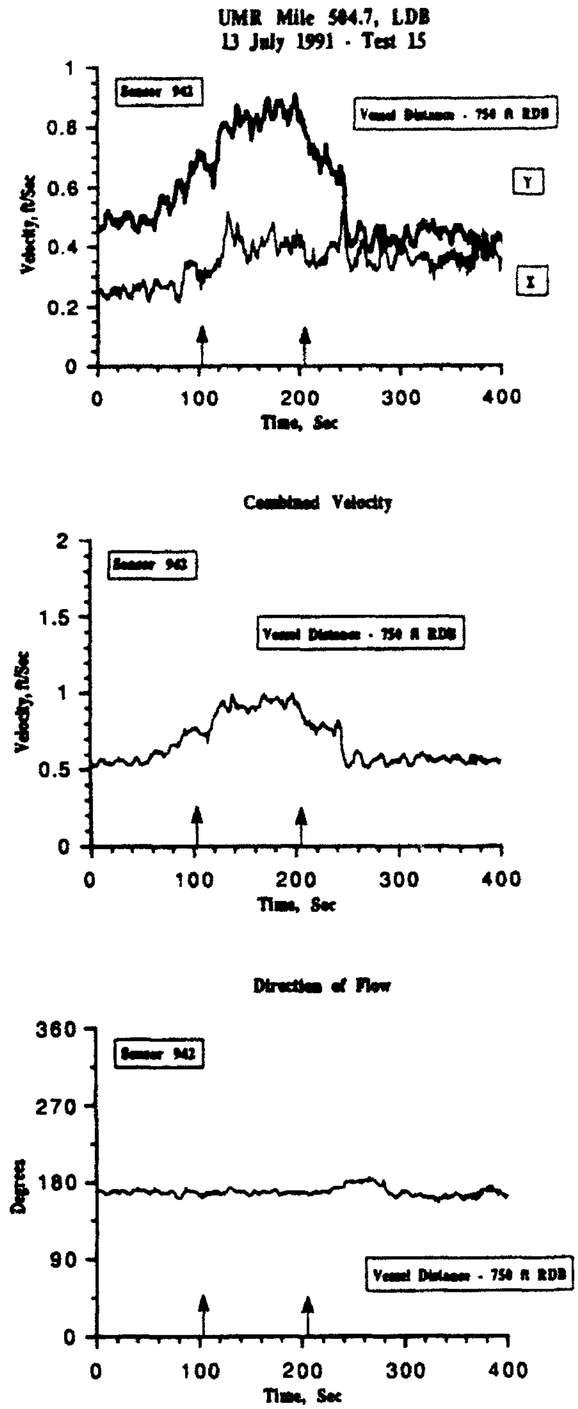


Figure E17. Test 15, RM 504.7, left descending bank (LDB), 13 July 1991

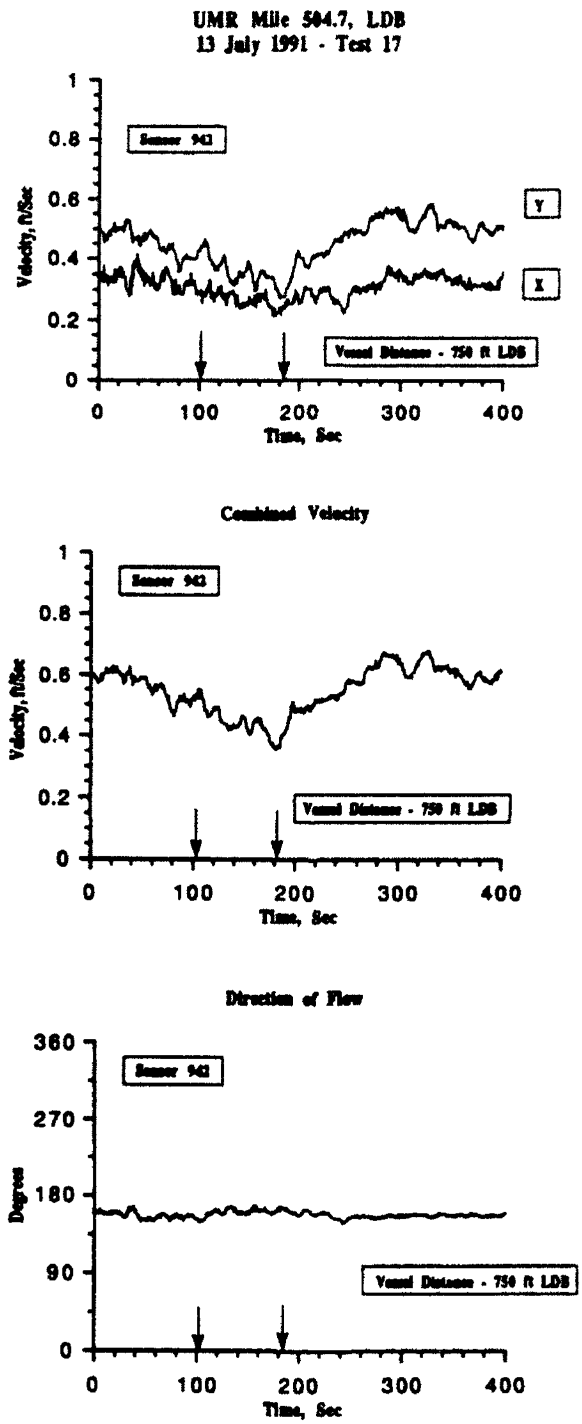


Figure E18. Test 17, RM 504.7, LDB, 13 July 1991

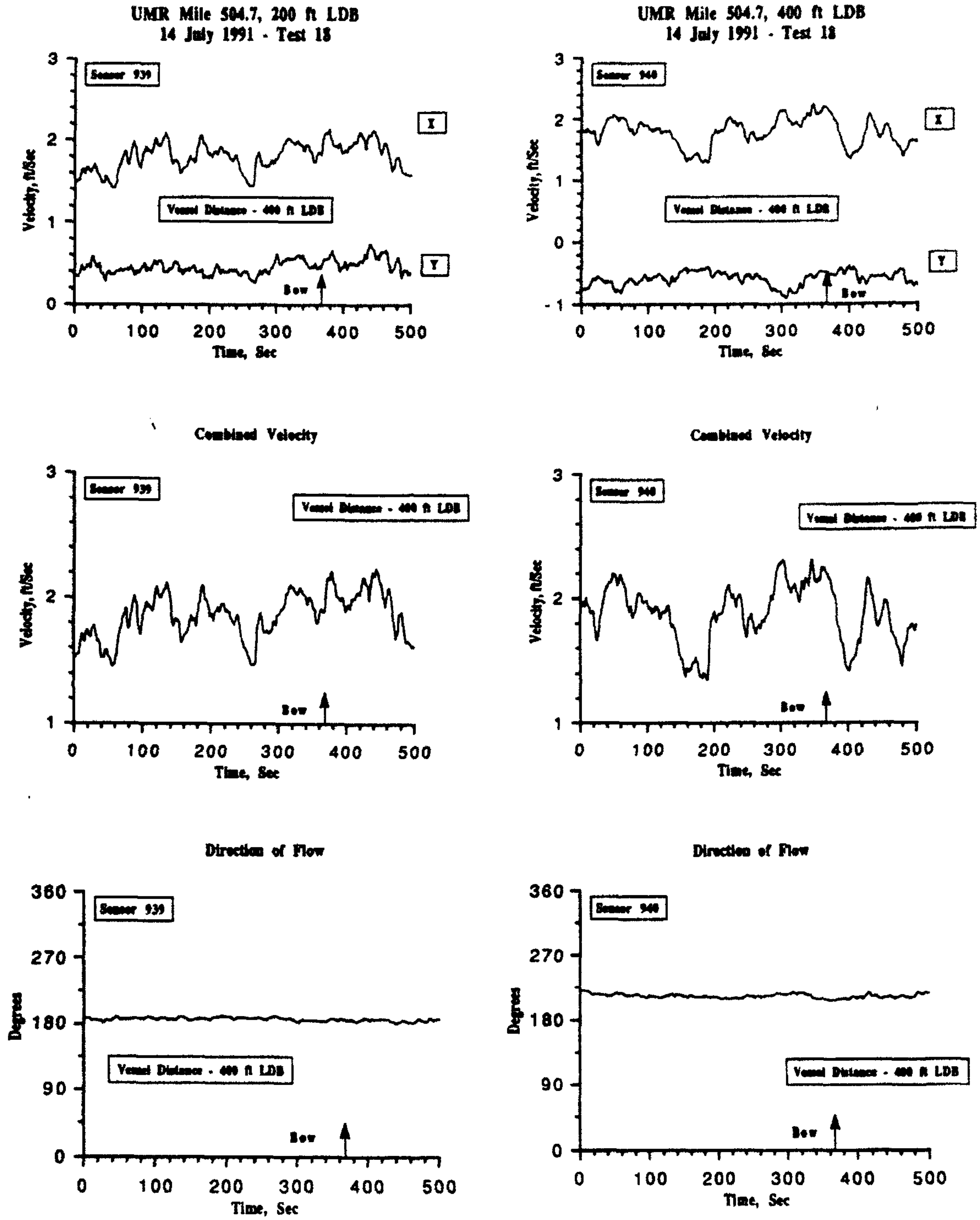


Figure E19. Test 18, RM 504.7, 200 and 400 ft LDB, 14 July 1991

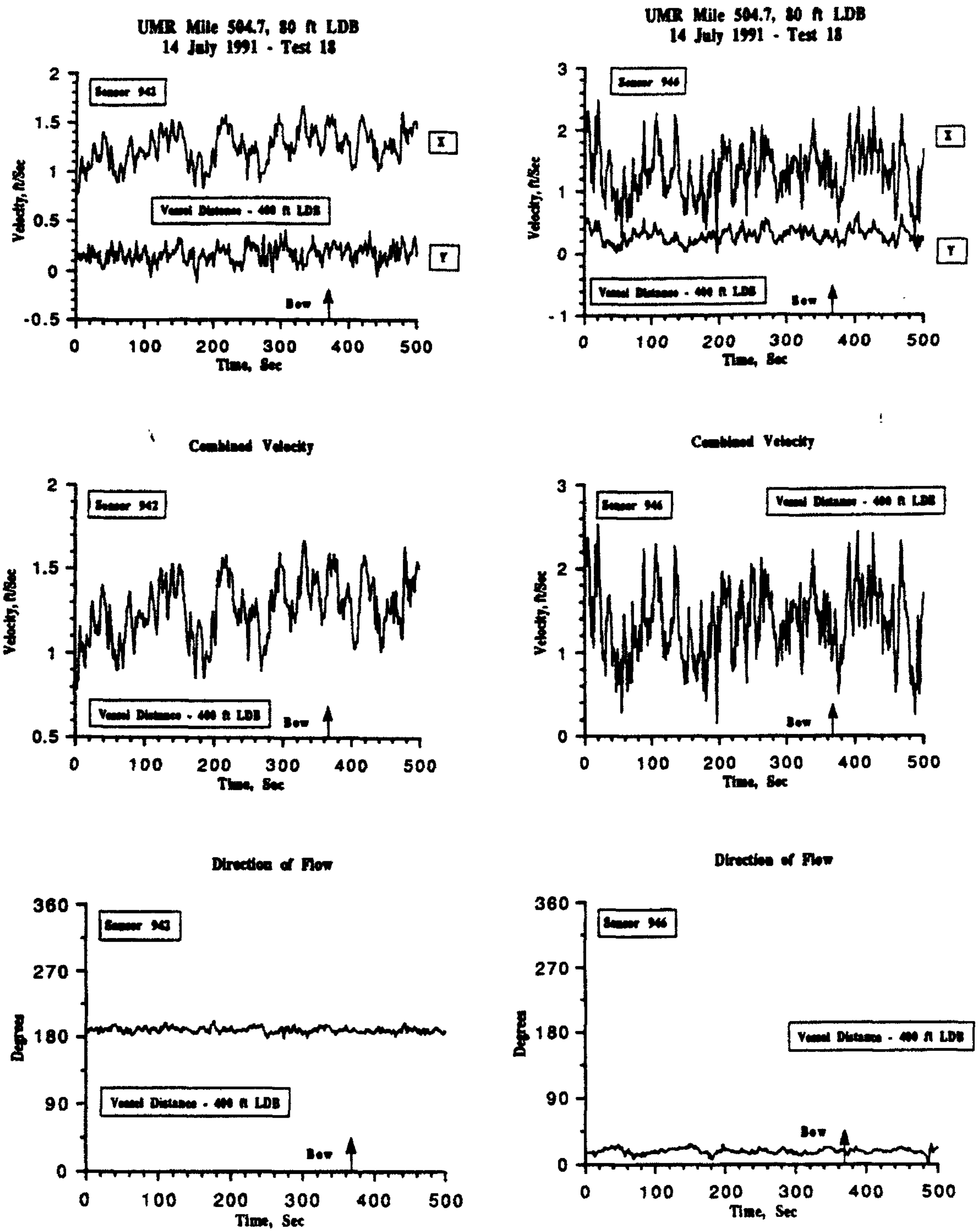


Figure E20. Test 18, RM 504.7, 80 ft LDB, 14 July 1991

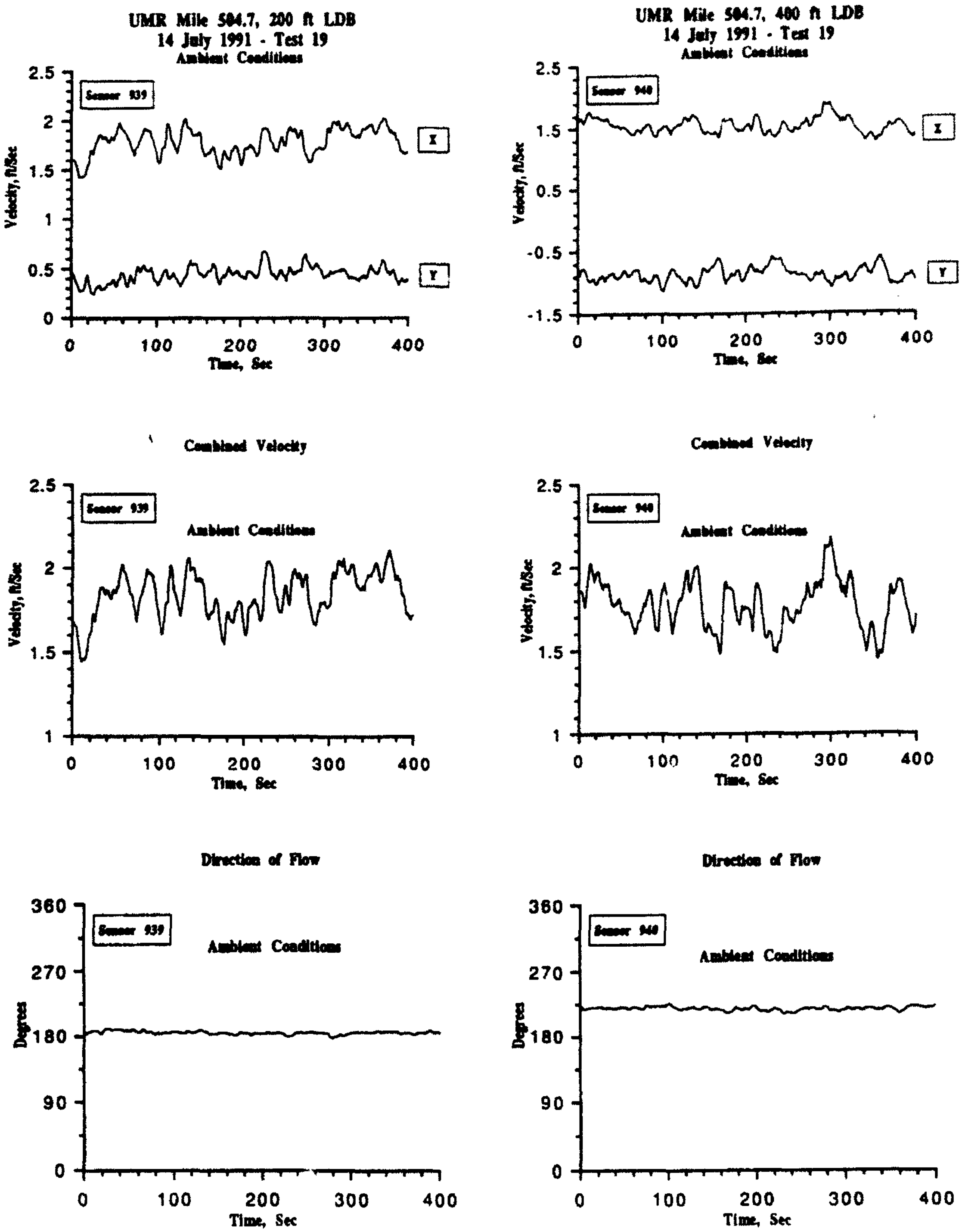


Figure E21. Test 19, RM 504.7, 200 and 400 ft LDB, 14 July 1991

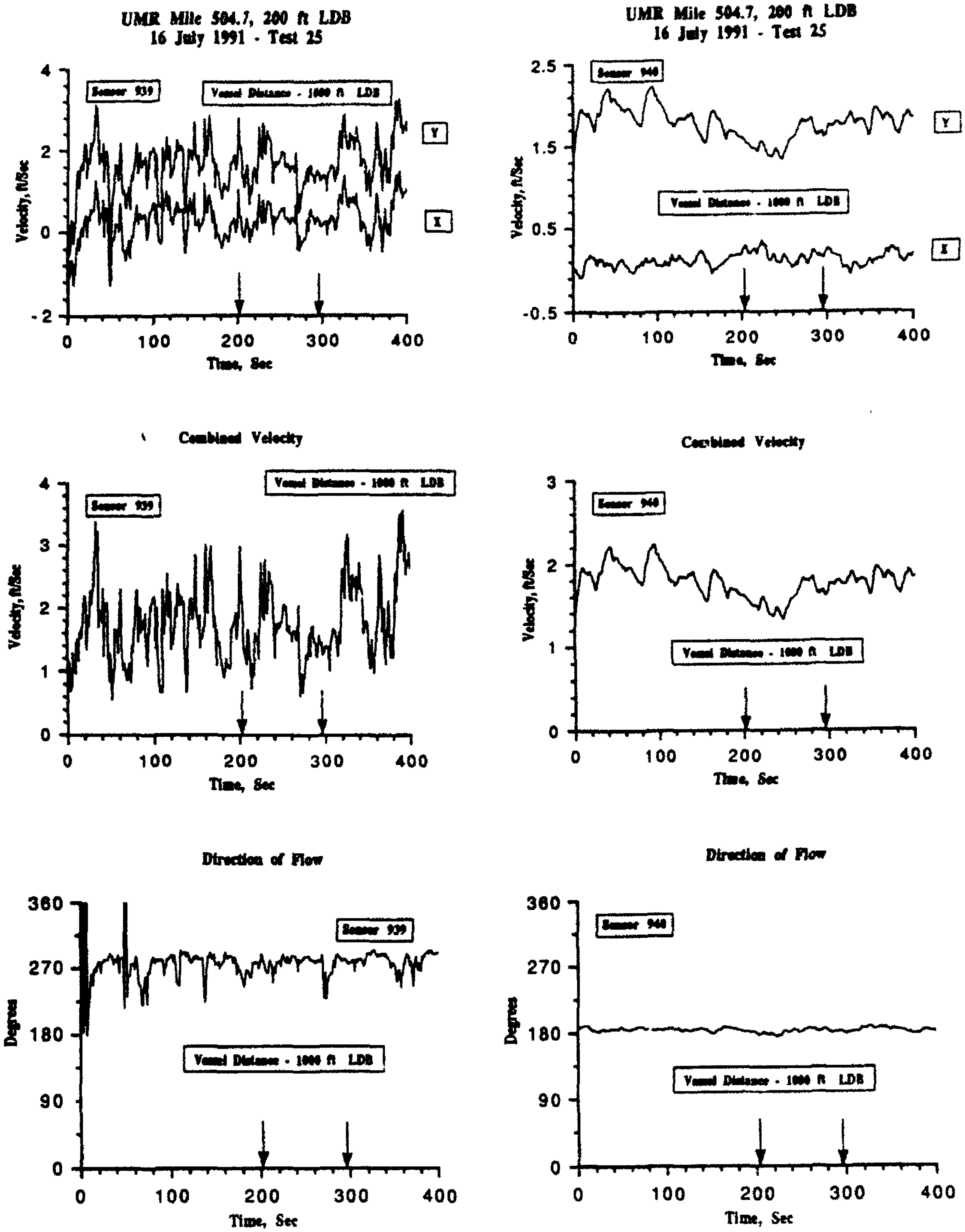


Figure E22. Test 25, RM 504.7, 200 ft LDB, 16 July 1991

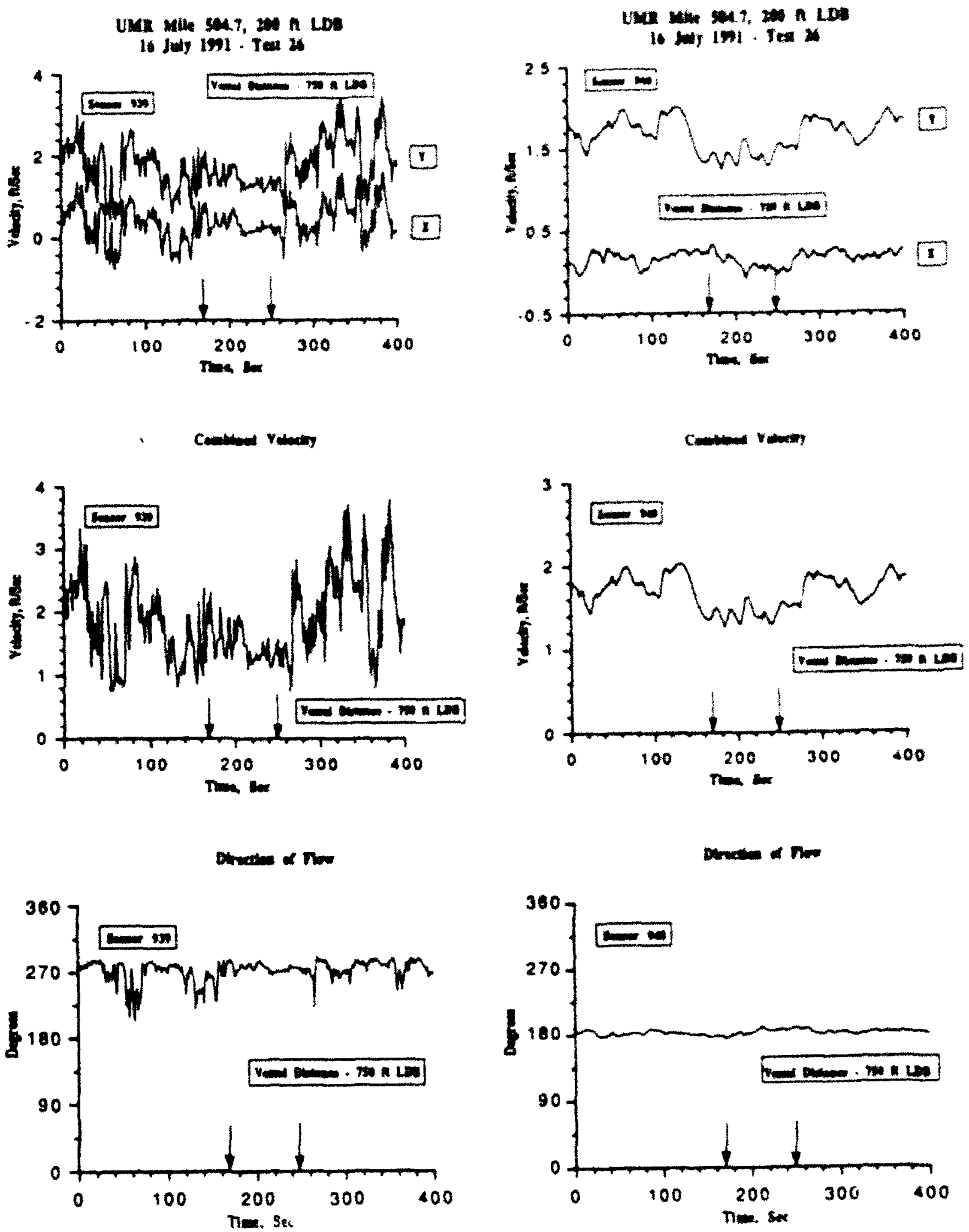


Figure E23. Test 26, RM 504.7, 200 ft LDB, 16 July 1991

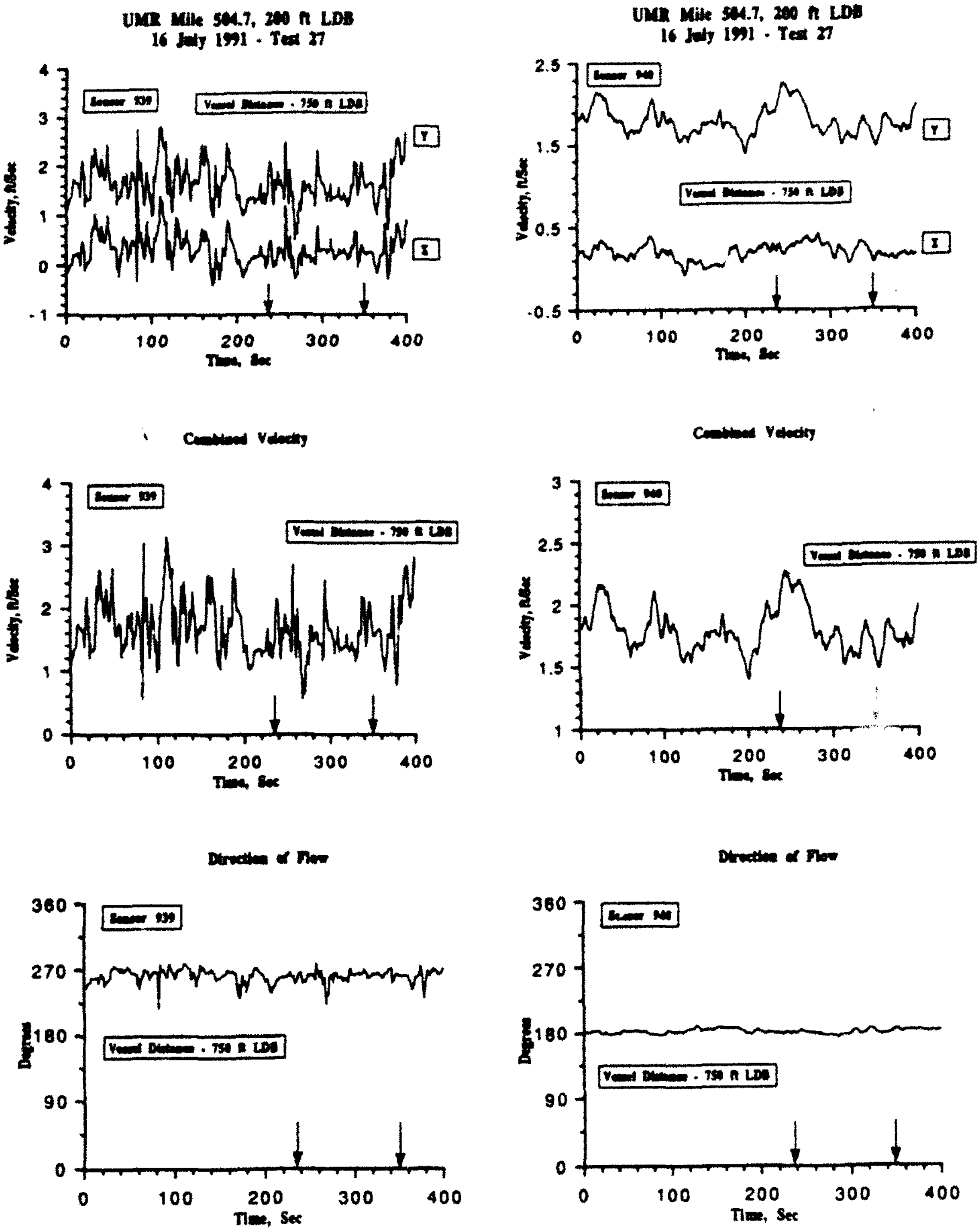


Figure E24. Test 27, RM 504.7, 200 ft LDB, 16 July 1991

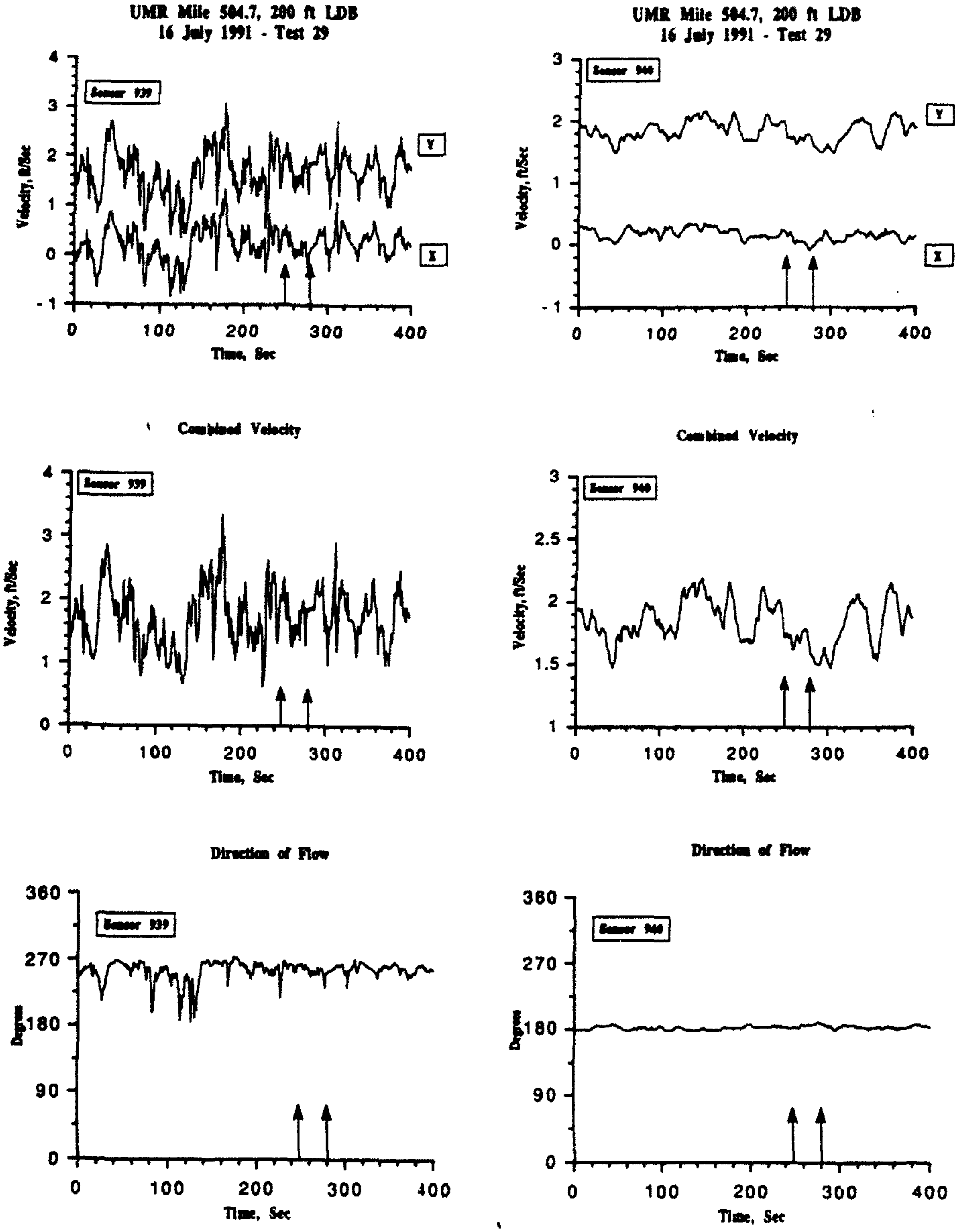


Figure E25. Test 29, RM 504.7, 200 ft LDB, 16 July 1991

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1993

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: 1991 Studies

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Waterways Experiment Station
Environmental Laboratory
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
EL-93-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Engineer District, St. Louis
1222 Spruce St.
St. Louis, MO 63103-2833

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

In 1988, the US Army Engineer District, St. Louis, initiated a program to analyze the effects of commercial navigation traffic on freshwater mussels (Mollusca: Unionidae), especially the endangered *Lampsilis higginsi*, in the upper Mississippi River. Preliminary studies were conducted in 1988; detailed studies were initiated in 1989 and will continue for at least 6 years. In July 1991, mussels were collected using qualitative and quantitative (0.25 sq m total substratum) methods at dense and diverse beds in Pool 24 (river mile (RM) 299.6), Pool 14 (RM 504.8), and Pool 10 (RM 635.2). Water velocity and suspended solids concentrations were measured immediately following vessel passage near sites where mussels were collected in Pools 24 and 10. An assessment of commercial navigation traffic effects will be based on a comparison of baseline data (1988-94) with data collected during periods of increased traffic intensity following 1994.

(Continued)

14. SUBJECT TERMS
Mississippi River
Mussels
Navigation traffic
Unionidae

15. NUMBER OF PAGES
137

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded)

In qualitative samples collected in 1991, *Amblema plicata plicata* dominated and comprised 41.02 percent of the fauna. Fifteen species were common and comprised from 8.73 to 1.57 percent of the collection, and 12 species made up less than 1 percent of the assemblage. Mean bivalve density (N = 30) was least in Pool 24 (5.1 to 35.1 individuals/sq m), moderate in Pool 10 (62.7 to 52.1 individuals/sq m), and highest in Pool 14 (81.4 to 84.8 individuals/sq m). *Lampsilis higginsi*, an endangered species, comprised 0.71 percent (14 individuals) and was found in nearly 10 percent of all qualitative samples. Velocity changes caused by vessel passages at sites where mussels were present in Pools 24 and 14 were either not measurable or minor. When measurable, vessels caused a surge or reduction in velocity of usually no more than double ambient velocity.

Six attributes of mussel beds were examined based on 4 years of sampling: (a) decrease in density of five common-to-abundant species, (b) presence of *L. higginsi* (if within its range), (c) live-to-recently-dead ratios for dominant species, (d) loss of more than 25 percent of the mussel species, (e) evidence of recent recruitment, and (f) a significant change in growth rates or mortality of dominant species. Based on sampling methods, these parameters are stable at beds in Pools 24, 14, and 10.